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Vol 1, pt. 2.

MARYLAND WATER SUPPLY AND DEMAND STUDY

Part II
FUTURE WATER SUPPLY AND DEMAND

Volume 1
THE REPORT

Prepared for
MARYLAND STATE PLANNING DEPARTMENT

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Consultants

April, 1965

STATE PLANNING DEPARTMENT
1103 State Office Building
Baltimore, Maryland 21201

Publication No. 132A

THE JOHNS HOPKINS UNIVERSITY · BALTIMORE, MARYLAND 21218

December 31, 1964

Mr. James J. O'Donnell, Director
State Planning Department
State Office Building
Baltimore, Maryland 21201

Dear Mr. O'Donnell:

We submit herewith a report on Future Demand and Supply of Water in Maryland, 1970 - 2010, which we have prepared for the State Planning Department under a grant from the U. S. Housing and Home Finance Agency.

Maryland is in the forefront of states which have instituted long range assessments of their vital water resources. We have welcomed the opportunity to undertake this study and to apply economic theory to resource evaluation and development in the State of Maryland.

In addition to those thanked collectively in the Preface to the Report, we would like to convey our appreciation for the unusually fine cooperation and professional capability of Dr. Albert Miller, Chief of Research and Special Studies, and Mr. Herbert Sachs, Project Planner, of the State Planning Department; contributions were also made early in the study by Mr. Joseph Szuleski and Mrs. Regina Seltzer of the State Planning Department staff.

It has been a pleasure to work with officials who place such a high value on professional standards and scientific objectivity in the interest of the people of the State.

Respectfully submitted,

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Associate Professor of Geography

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MARYLAND WATER SUPPLY AND DEMAND STUDY

STATE OF MARYLAND

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The preparation of this document was financially aided through a Federal grant from the Urban Renewal Administration of the Housing and Home Finance Agency, under the Urban Planning Assistance Program authorized by Section 701 of the Housing Act of 1954, as amended.

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PREFACE

If this report were taken as a final word or blueprint for water development in Maryland, we would have failed in our purpose. We emphasize that resource planning is a process, with goals continually undergoing revaluation, technological relations continually changing, and knowledge continually expanding. Under these circumstances we have tried to present a method of looking at water supply and demand into which changes in data or purpose can be incorporated over the years to come.

During the period in which research was being conducted on this study the list of those who provided data, advice, and critical comments grew very large. Rather than try to name all of those who were of help (and run the attendant risk of omitting some) we hereby thank all of them - colleagues, students, officials and staff of local, state, and Federal agencies, and others who have helped. It is appropriate to emphasize our debt to the members of the Technical Advisory Committee with whom periodic meetings were held throughout the study, and to make clear that the final product is our responsibility alone. We would also like to thank explicitly the students who contributed directly to research, computations, and, in some cases, writing: Takeshi Amemiya, Charles Blackorby, Byron Brown, Jacquelyne Bullock, John Iton, Michael Lav, Margaret McPherson, Sherry Hessler Olson, Ethan Smith, Azriel Teller, and David Warheit. Mrs. William McDonnell acted as editorial assistant, while the arduous typing of text and tables was done by Mrs. Susan Carlin and Mrs. Sharon Sekulich.

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CHAPTER I

INTRODUCTION

A. Purpose of the study

This report is a study of water demand and supply in Maryland during the coming decades. Specifically, its purpose is to project the future demands for each of the major categories of water users, to compare these demands with available supplies, and to recommend desirable forms of water resource development and ways of allocating the available water supplies.

Public and private concern with water resource problems has grown dramatically during the last decade or two. The rapid growth of population and economic activity since World War II has led to large increases in the use of water for various purposes and in the amounts of wastes discharged into streams. We have thus become painfully aware that pure water is no longer a free good, available in almost limitless supply. Instead, pure water is a valuable resource whose use must be allocated among many competing demands.

Concern with the allocation of scarce water resources has led to a rapid growth of interest in the application of the tools of economic and regional analysis to water resource problems. Research concepts and techniques have improved gradually as experience with the problems has accumulated. By far the most careful and comprehensive study of national water resource problems is that undertaken by the U.S. Senate Select Committee on

National Water Resources, under the chairmanship of Senator Kerr.[1] The Kerr Committee study has provided a national framework within which more detailed studies such as this one can be carried out.

The reason that it is important and useful to undertake economic analysis of water resource problems is that there is a wide range of alternative ways in which water resources, like any other resource, can be developed and used. There is a popular belief that the available supply of water is fixed by rainfall and other natural events, and that the demand for water is determined by rigid needs. However, this belief is far from the truth. Both the demand for and supply of water can be varied within wide limits,depending on how much money and resources are devoted to making water available and to economizing the use of it. The relevant dimensions of water demand and supply are quantity, quality, time and place, all of which can be affected by the use of complementary or substitute resources. One example each from the demand and supply sides will illustrate.

On the supply side, streamflow varies greatly from season to season. In many streams, the flow during the month of highest flow may be ten to twenty times the flow during the month of lowest flow. Furthermore, the greatest uses of water tend to coincide with the periods of low flow, in late summer. Typically, the available supply is increased by the construction of dams and reservoirs that fill during periods of high flow and thus

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1. Water Resource Activities in the United States, Committee Prints 1-32. Select Committee on National Water Resources, U.S. Senate, 86th Congress, 1st Session. U.S. Government Printing Office, 1959, 1960. Throughout this report, we will refer to this document simply as the Kerr Committee Report. The economic analysis for the Kerr Committee study was under the direction of Nathaniel Wollman, who has expanded his research in a forthcoming Resources For the Future volume.

increase the available supply during periods of low flow. Thus, the available supply of water can be increased within wide limits by devoting more resources to the collection and storage of water.

On the demand side, one of the major uses of water is for industrial cooling. The amount of water withdrawn for this purpose can be reduced greatly by the use of recirculating equipment. Furthermore, water of one quality can be substituted for water of another quality. The latter phenomenon is illustrated by the rapid growth in recent years of the use of saline water from estuaries. Thus, variation is possible in both the amount and quality of water used for industrial cooling. In each case, economy is realized in the use of water by the use of other productive inputs that substitute for water. In the first case, recirculating equipment is a substitute for water withdrawals. In the second case, the use of corrosion-resistant materials permits the substitution of relatively plentiful low-quality saline water for scarce high-quality fresh water.

Thus, the focus of this report is on choices among available alternatives in the development and use of water resources. The realization that water supply and demand are not rigidly inflexible should not lead us to the opposite fallacy of thinking that water resource problems are unimportant. Water is an important resource. Substantial increases in supply can be very costly. Furthermore, mistakes in the development and allocation of water resources can be expensive and unpleasant. Excessive stream pollution, for example, has been a major misuse of water resources in many parts of the country in recent years.

Finally, water resource activities are a complicated mixture of private and public decisions. Although many water resource decisions are and should be private, some of the most basic decisions are necessarily public. Major water supply developments through regulation of streamflow are usually in the public domain. In addition, the control of waste discharge and waste pollution are necessarily matters of public policy since no market exists on which to register the costs (to subsequent users) and benefits (in the form of lower treatment costs to those who generate wastes) of the discharge of wastes into streams. Because of the wide variety of choices available, the cost of extensive water resource development, and the costly nature of mistakes, public decisions should be based on careful economic analysis of costs and benefits of alternative plans.

B. Scope and procedure

Geographically, the scope of this report is limited to the State of Maryland. This leads to some difficulties since drainage basins and political boundaries are by no means coincident. Ways of handling these problems are discussed in detail in subsequent chapters.

The period covered extends to the year 2010, with detailed projections for the years 1970, 1980, and 2010. Forecasting of major economic and demographic quantities is a hazardous occupation, and no one should place great confidence in the accuracy of forecasts covering nearly half a century. Therefore, our projections and analysis for 2010 should be viewed as no more than rough guides which will hopefully portray the bare outlines of the major water resource problems that the State will face at that time. However hazardous, it is necessary to attempt long-range forecasts because of the long useful lives of such projects. Most current policy problems, however, are much more closely related to developments that will take place during the next decade or two. Furthermore, much more reliance can be placed on forecasts of a decade or two into the future than on those covering half a century.

In order to make projections and analysis of supply and demand more realistic, it is necessary to divide the State into several smaller areas. Considerable thought was given to the best division for our purposes. From the point of view of water availability, classification by major river basins is desirable. From the point of view of use, classification into economic areas is desirable. From the point of view of data availability, classification along political boundaries is desirable. Considering all these factors, the best procedure appeared to be a division of the State into five major regions, based mainly on economic, demographic and political boundary considerations. The regions, shown on Figure 1, are:

Region I, Southern Maryland: Calvert, Charles, St. Mary's Counties;

Region II, Western Maryland: Allegany, Frederick, Garrett, Washington Counties;

Region III, Baltimore metropolitan area; Baltimore City and Anne Arundel, Baltimore, Carroll, Harford, Howard Counties;

Region IV, District of Columbia metropolitan area; Montgomery, Prince George's Counties;

Region V, Eastern Shore: Caroline, Cecil, Dorchester, Kent, Queen Anne's, Somerset, Talbot, Wicomico, Worcester Counties.

Substantively, the terms of reference of the study are restricted to fresh water, including both surface and, when data are available, ground water. In practice, it has been neither possible nor desirable to exclude considerations of brackish and salt water use altogether. At present, there are two major uses in which fresh and brackish or salt water are substituted for each other. One, as indicated in the example in Section 1, is industrial water use. The other is recreation. The relevance to these two water uses

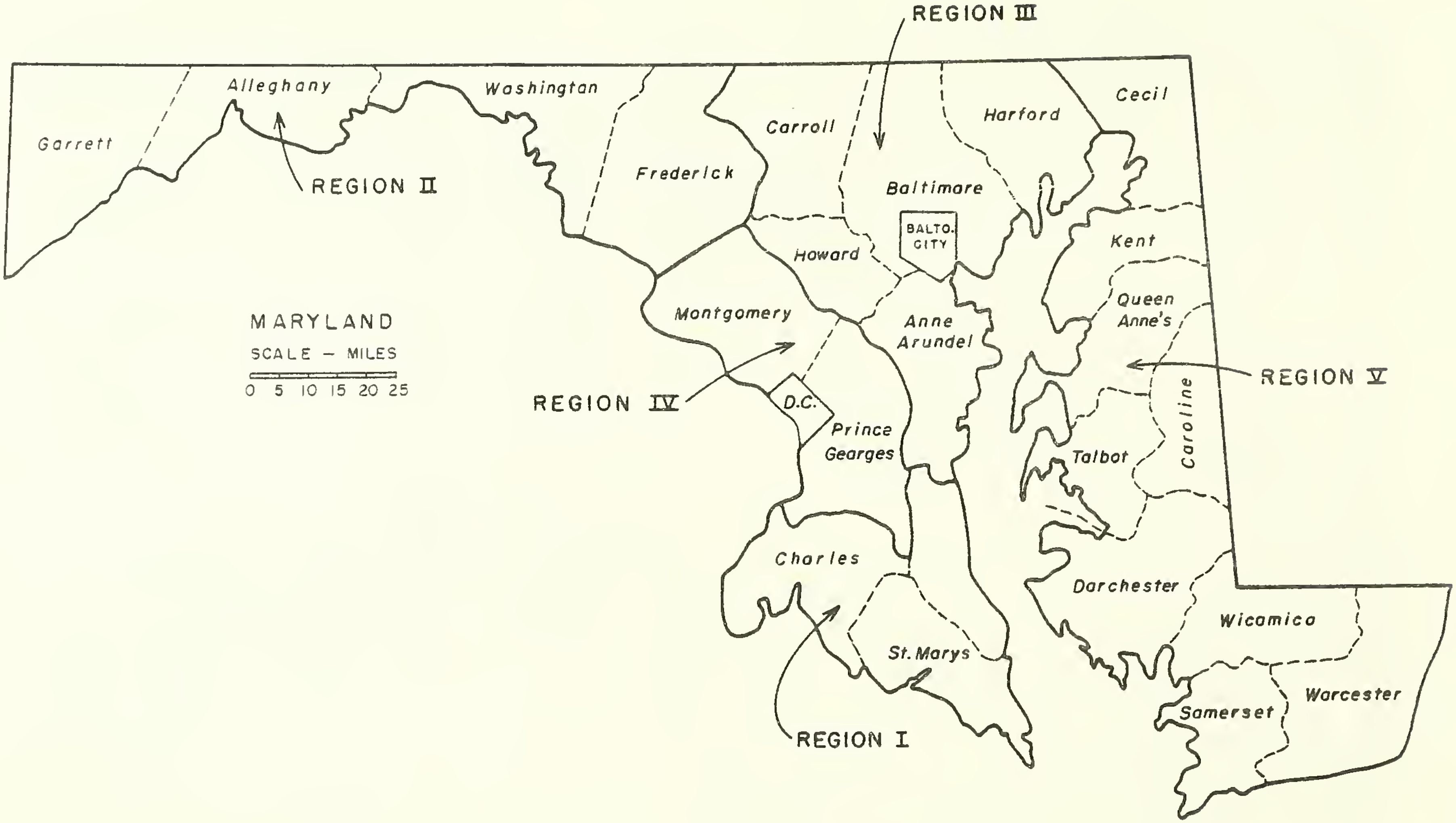

Figure 1

Maryland Regions Used in Study

of the availability of large quantities of salt and brackish water is discussed in detail in subsequent chapters. Another major relationship between fresh and saline water results from the possibility of desalinization. Although technically possible, it is unlikely that desalinization will be an economical method of obtaining large amounts of fresh water in a humid state such as Maryland in the foreseeable future.

Throughout the report, certain basic terms will be employed relating to the use of water. Most popular statistics relating to water use are for amounts withdrawn from surface or ground water. Much more relevant for economic analysis, however, are amounts consumed or depleted, and we must be clear as to the meanings of these terms. Many different definitions of water consumption or depletion appear in the literature, but most are too narrow for our purposes. The economically relevant definition of depletion is water that is withdrawn and made unavailable for further use. Water may be unavailable for further use because it is not returned to a natural body at all. This occurs when the water is evaporated or transpired into the atmosphere as a result of withdrawal, or when it is incorporated into a product. Such uses are clearly consumptive. However, uses may also be consumptive, in the economically relevant sense, if discharges are at a different time or place, or of a sufficiently lower quality than withdrawals. Time, place and quality can all make water unavailable for further use. Time is crucial when water is withdrawn from a stream and discharged into the ground. Although such water may eventually become available for further use, the time lag may be so long and uncertain as to make the withdrawal consumptive for economic purposes. Place is crucial when water is withdrawn from one basin and discharged into another. Quality may be crucial if the water withdrawn is returned with biological or chemical pollutants, if it is much warmer than when withdrawn, or if it is discharged into saline bodies. The last factor is particularly important in Maryland, since major population centers are located on or near estuaries. In such cases, a large part of fresh water withdrawals is discharged into saline bodies and is therefore consumptive in the relevant sense. Indeed, discharge into saline bodies is the major consumptive use of water in Maryland. The effects of discharge of fresh water into saline bodies on the reuse of water, and on fresh water flows needed for quality maintenance, are analyzed in detail in subsequent chapters.

Consumptive uses discussed in the previous paragraph compete for available water supplied, not only with each other but also with certain instream uses of water. The latter include streamflow for water quality maintenance, for navigation, hydroelectric power generation, recreation, and the maintenance of proper salinity in estuaries. Some of these factors, such as navigation, are unimportant in Maryland fresh water streams. Others are discussed in detail in subsequent chapters.

The outline of the report is as follows: Chapter II presents the basic population and employment projections on which all the subsequent projections and analysis are based. Chapters III-V present projections of water use for each of the major categories of fresh water users. Chapter III is concerned with water use by municipalities for household, commercial, public and other uses. Chapter IV is concerned with major water-using industries. Chapter V is concerned with water use in agriculture. Chapter VI is concerned with the relationship between recreation and water use. Recreation involves some withdrawal uses and some instream uses of water. Chapter VII presents projections of wastes generated from municipal and industrial activities. It then analyzes the relationship between the treatment of wastes and the dilution of wastes by streamflow. Chapter VIII brings together and summarizes all the demands in both the withdrawal and instream categories. Chapter IX analyzes the concept of supply and presents the relationships between supply and the development of reservoir storage capacity. Finally, in Chapter X, the demand and supply sides are brought together and the calculations of optimum water resource development are presented. In Chapter XI, all the recommendations arising from the study are presented and discussed.

CHAPTER II

POPULATION AND EMPLOYMENT PROJECTIONS

A. Introduction

The purpose of this chapter is to present our projections of Maryland's future population and employment. The classifications and the level of detail employed in these projections are determined mainly by the need to use them in subsequent chapters as building blocks in projecting demands by major water-using groups. Household, commercial, municipal and recreational uses of water are closely related to population. Industrial water use is closely related to employment. However, since water demand per employee varies greatly from industry to industry, it is necessary to project employment by a rather detailed industrial classification. Attention can then be focused on the major water-using industries in later chapters.

There has been some discussion in the past as to whether employment or population is the more fundamental variable. One point of view is that the presence of a large population creates employment opportunities, and therefore an employment projection should be a corollary of a population projection. The opposite point of view is that employment opportunities attract population and therefore a population projection should be a corollary of an employment projection. But this is a false issue, for in a general theory of location, the location of both population and employment would be determined simultaneously. In other words, we believe that both forces are at work. The availability of employment certainly attracts population and, furthermore, the presence of population certainly creates employment opportunities. Therefore, our procedure has been to project population and employment independently as an initial step. We then compared the two sets of projections to see whether they implied reasonable projections of labor force participation rates. In cases where they did not, we re-examined the initial projections and modified them to the extent that appeared reasonable.

All large-scale projections involve extrapolation of past trends in one way or another. Implicit in such projections is the assumption that no drastic changes will reverse the historical trends during the forecast period. Thus, this report's employment and population projections assume that there will be no major wars or depressions and no revolution in the technology of production or transportation that would drastically alter the structure of metropolitan areas. Furthermore, the projections assume that the growth of employment and population will not be hampered by a scarcity of high quality water. If the resulting projections of water demand and supply were to show that sufficient water could not be made available at reasonable cost, then revision of the projections would be necessary.

For any geographical area, population growth is the sum of natural increase (excess of births over deaths) and net immigration. For the country as a whole, the latter is established as a matter of political policy and is likely to be of small importance in the coming decades. For a small area such as Maryland, however, it is of critical importance in projecting population growth.

Since the early 1930's, Maryland employment and, more so, population have grown more rapidly than employment and population in the country as a whole, and the rate of growth has been accelerating over most of this period. In the decade of the 1930's, Maryland's population grew 11.6 percent, whereas the U.S. population grew 7.2 percent. In the 1940's, the figures were 28.6

percent and 14.5 percent. In the 1950's, they were 32.3 percent and 19.0 percent. The result has been that Maryland's population has grown from 1.38 percent of the U.S. population in 1940 to 1.74 percent in 1960. Employment has shown a similar trend.

This rapid relative and absolute growth has resulted from three major factors. First, Maryland has shared in the rapid rise in birth rates and the gradual fall in death rates that have occurred in the country as a whole since the 1930's and particularly since 1945. Second, Maryland has been a large net recipient of population as a result of the nationwide migration of people from rural to urban areas in recent decades. People have come to Maryland chiefly from the southeastern states and from the area now popularly referred to as Appalachia. Third, Maryland's population has grown substantially as a result of the growth of the federal sector of the economy since the 1930's. That growth has resulted in a large influx of people to the Washington, D.C. area: postwar suburbanization, which Washington has shared with other large cities, has resulted in rapid growth in the Maryland suburbs of the Washington area.

At least the second and third of these factors are closely related to the availability of attractive employment opportunities. Thus, employment, like population, has grown rapidly both absolutely and relatively in Maryland during recent decades. Since the mid-1950's, however, employment has grown somewhat less rapidly than population. Thus, from 1947 to 1957 Maryland's share of total U.S. employment grew from 1.52 percent to 1.65 percent. By 1960, however, Maryland's share had fallen to 1.61 percent. Thus, although Maryland's population continued to grow more rapidly than U.S. population at least until 1960, Maryland's employment grew less rapidly than U.S. employment in the latter part of the 1950's. This disparity was mainly the result of the rapid increase in the number of people who live in the Maryland suburbs of Washington, D.C. and work in Washington.

In order to project future growth in Maryland's population and employment, one must ask to what extent the factors responsible for recent growth will continue to be important in the coming decades. The first factor listed above, high birth rates and falling death rates, is almost certain to contribute less to population growth in the coming decades than it has in the last two decades. Although it is reasonable to assume that death rates will continue their gradual decline, birth rates are unlikely to remain at their high postwar levels during the coming decades. Birth rates have been falling slightly but steadily throughout most of the country as well as in Maryland since 1957. This trend is likely to continue in the foreseeable future, although it is impossible to know how far birth rates will ultimately fall. The second factor, migration from rural to urban areas, is likely to continue in the foreseeable future, although not necessarily at the rate observed during the postwar period. Furthermore, it is possible that in the coming decades migration from the rural Southeast and Appalachia will be increasingly in the direction of the industrializing urban centers in the South rather than to border cities such as Baltimore and Washington. The third factor, rapid relative growth of the federal sector, is also likely to decrease in importance during the coming decades. Barring any drastic and prolonged international crisis, the federal sector of the economy is unlikely to grow relative to the economy as a whole during the coming decades. Indeed, from 1953 to 1962, Federal Government expenditures fell from 15.9 percent of Gross National Product to 11.2 percent. Although there is unlikely to be much more relative decline, there is unlikely to be much relative growth of the federal sector either. Nevertheless, reasonable projections of population growth in the Washington, D.C. metropolitan area indicate substantial growth in the coming decades, and it is likely that most of this growth will take place in the Maryland and Virginia suburbs.

B. Population

In projecting Maryland's population, a variety of existing projections for the State and the Baltimore and Washington, D.C. Regions were consulted. These projections are summarized in Table 1. It is not surprising that these projections show much more agreement up to 1980 than they do for subsequent years.

After careful consideration, it was decided that a modified version of the Resources for the Future projections would be best for our purposes. On the basis of a single set of high, medium and low national projections, RFF made two sets of state projections. The set shown in Table 1 is based on a low migration assumption, implying that the high rates of interstate migration observed recently will decline rather rapidly. The other set, not shown, is based on the assumption that migration rates will decline much more slowly. We believe that for the country as a whole, the high migration assumption is the better one. However, for Maryland, we believe that the low migration assumption is better, since a continuation of the recent rate of immigration into Maryland can hardly occur unless the federal sector continues to grow as rapidly as it did from 1940 to the mid-1950's, and as argued in Section A, this is an unlikely possibility.

The modification that we made in the RFF low migration projections was to place them on a 1960 base by applying RFF's projected population growth

TABLE 1

Alternative Population Projections
(000)

	(Actual) 1960	1970	1980	1990	2000	2010
			MARYLAND			
State Plan. Dept. (1963)[3]	3,101	3,838	4,542	5,038	5,500	
U.S. Census (1957)[4]	3,101	1. 3,970 2. 3,844 3. 3,760 4. 3,616				
U.S. Census (1960)[5]	3,101	II-1 4,027 II-2 3,847 IV-1 3,824 IV-2 3,646	II-1 5,188 II-2 4,851 IV-1 4,641 IV-2 4,323		II-1 8,011 II-2 7,372 IV-1 6,223 IV-2 5,694	
RFF (1960)[6]	3,101	High 4,016 Med. 3,747 Low 3,638	High 5,191 Med. 4,559 Low 4,206		High 8,358 Med. 6,388 Low 5,174	
Natl. Plan. Ass. (1961)[7]	3,101		4,319 (1976)			
			BALTIMORE REGION[1]			
Balto. Reg. Plan. Coun. (1960)[8]	1,804		High 2,650 Med. 2,545 Low 2,435			
Balto. Reg. Plan. Coun. (1962)[9]	1,804		2,659			
			WASHINGTON, D.C. REGION[2]			
M. Hoffman Ass. (1962)[10]	2,002		3,415			
Natl. Cap. Plan. Com. (1961)[11]	2,002		3,200		5,000	
O.B.E., H.E.W. (1960)[12]	2,002			3,350 (1985)		5,000

Notes to Table 1:

1. Same as Region III. See Chapter I.
2. Includes Washington, D.C.; Prince George's and Montgomery Counties in Maryland; Alexandria and Fairfax, Prince William and Loudon Counties in Virginia.

Sources:

3. Newsletter, Department of Planning, July 1963.
4. Current Population Reports, U.S. Census, P-25, No. 187, 1958. Numbers designate alternative projections.
5. Kerr Committee Print No. 5. Numbers designate alternative national projections and migration assumptions.
6. Kerr Committee Print No. 5.
7. Projections to the Years 1976 and 2000: Economic Growth, Population, Labor Force and Leisure, and Transportation, Outdoor Recreation Resources Review Commission, Study Report 23.
8. Housing Market Analysis, Maryland State Planning Department, Baltimore Regional Planning Council, Technical Report No. 6.
9. Unpublished.
10. Report on Downtown Housing Market, Washington, D.C., 1962.
11. A Policies Plan for the Year 2000. The Nation's Capital, National Capital Planning Commission, 1961.
12. Economic Base Survey of the Potomac River Service Area, Department of Commerce, 1961.

rates to the actual 1960 Census measure of population. The resulting modifications of the RFF projections are small.

The basic procedure for allocating the projected State population to the five sub-regions was as follows: The Maryland State Planning Department projections shown in Table 1 are available on a county basis. We calculated the percent distribution of their projections to the five sub-regions and multiplied these percentages by the RFF State projections. Then a number of slight modifications were made in this sub-region distribution to allow for our judgment as to how far the Baltimore and Washington, D.C. Metropolitan Regions would extend in the coming decades.

Population projections are shown in Table 2. They imply that Maryland's population in 2010 is likely to be between 5.6 million and 10.1 million, with a medium projection of 7.4 million. Each projection implies a rapid percentage growth in the near future, and a decreasing rate of growth in the more distant future. The medium projections, for example, imply a 22.5 percent growth from 1960 to 1970, falling off to a 15.0 percent rate of growth from 2000 to 2010. The medium projections imply that Maryland's population in 2010 will be 2.4 times its 1960 level.

All three projections imply that most of Maryland's future population growth will take place in the Baltimore and Washington, D.C. metropolitan areas. In 1960, 80.5 percent of the population lived in the Baltimore and Washington areas. Our medium projections imply that this figure will rise slightly to 83.8 percent by 2010. As these two regions grow, some of their population will spill over into Southern and Western Maryland, particularly into Charles and Frederick Counties.

TABLE 2

Maryland Population Projections (000)

By Sub-Regions, Actual 1960; Projected 1970-2010

Region	1960	1970	1980	1990	2000	2010
			High			
I - Southern Md.	87	117	154	209	282	356
II - Western Md.	268	296	345	425	539	676
III - Baltimore Metro.	1,804	2,217	2,833	3,526	4,426	5,381
IV - Washington Metro.	698	1,073	1,472	1,954	2,528	3,080
V - Eastern Shore	244	283	349	425	523	630
Maryland	3,101	3,985	5,153	6,539	8,298	10,124
			Medium			
I - Southern Md.	87	111	138	175	220	262
II - Western Md.	268	282	310	357	421	497
III - Baltimore Metro.	1,804	2,113	2,542	2,952	3,457	3,967
IV - Washington Metro.	698	1,023	1,320	1,634	1,974	2,265
V - Eastern Shore	244	271	313	356	408	464
Maryland	3,101	3,799	4,623	5,474	6,481	7,453
			Low			
I - Southern Md.	87	107	127	151	178	199
II - Western Md.	268	272	285	307	340	378
III - Baltimore Metro.	1,804	2,044	2,336	2,541	2,787	3,000
IV - Washington Metro.	698	989	1,213	1,406	1,591	1,714
V - Eastern Shore	244	261	288	306	329	351
Maryland	3,101	3,675	4,248	4,711	5,224	5,642

Growth Rates, Medium Projections

Region	1960	1970	1980	1990	2000	2010
I - Southern Md.	-	27.6	24.3	26.8	25.7	19.1
II - Western Md.	-	5.2	9.9	15.2	17.9	18.1
III - Baltimore Metro.	-	17.1	20.3	16.1	17.1	14.8
IV - Washington Metro.	-	46.6	29.0	23.8	20.8	14.7
V - Eastern Shore	-	11.1	15.5	13.7	14.6	13.7
Maryland	-	22.5	21.7	18.4	18.4	15.0

C. Employment

Employment statistics are harder to use than population statistics because the definitions used depend to a considerable extent on the purpose for which the statistics are collected. The most relevant definition of employment for our purposes is a broad one. It is the annual average of all persons engaging in economic activity, including self-employed, agricultural proprietors, domestic service workers, and government employees as well as wage and salary workers, but excluding military personnel.

By far the most careful and comprehensive employment projections available are those made by the National Planning Association to 1976.[1] The technique used by NPA consisted of a careful projection of U.S. population by age group, consideration of trends in labor force participation by age and sex, and an allowance for 4 percent frictional unemployment. The share of employment in particular states was examined for historical trend, but, more particularly, the composition of employment among slowly and rapidly growing industries was taken into account. In addition, location factors in some key industries were assessed to anticipate major shifts in geographical patterns of employment.

We have adopted a modification of the NPA projections for Maryland as our medium projections to 1976. Modifications have been made to allow for sub-regional differences in unemployment rates, to allow for a gradual reduction in unemployment to the 4 percent level assumed by NPA, and to achieve consistency with our population projections presented in the previous section. Maryland is one of the few states in the eastern part of the country whose share in national employment will increase by 1976, according to NPA projections. Our projections from 1976 to 2010 were made by extrapolating the trend in Maryland's share of the U.S. employment and assuming that it will grow at a decreasing rate after 1976.

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[1] State Employment Trends to 1976, National Planning Association Regional Economic Projection Series, Report No. 1, 1962 Edition. Also see, Projections to the Years 1976 and 2000: Economic Growth, Population, Labor Force and Leisure, and Transportation, Outdoor Recreation Resources Review Commission, Study Report No. 23.

NPA, and other projections are by place of work. In order to check our employment projections for consistency with our population projections we must also have employment projections by the employed's place of residence. Fortunately, the 1960 U.S. Census contains data on commuting which makes it possible to make the required adjustments.

Our projections of employment by place of employment are presented in Table 3. Projections of employment by place of residence are in Table 4. Projections of unemployment rates are in Table 5. Labor force participation rates are presented in Table 6. Tables 7 and 8 present the percentage distribution of employment by place of employment and by place of residence among the five sub-regions.

As stated in section A, a further breakdown of employment is necessary in order to focus attention on major water-using industries in later chapters. Water use is heavily concentrated in about a half-dozen manufacturing industries, and these will be of primary concern in the chapter on industrial water use. Here, however, we present a complete breakdown of the percentage composition of employment by nine major industry categories. These are shown in Table 9. The figures in Table 9 assume a continuation of the trend that has been observed in Maryland and the rest of the U.S. toward a gradual reduction in the percentage of employment that is in manufacturing. Thus, we

TABLE 3

Projections of Total Employment by Place of Employment For Maryland and Sub-Regions, Projected 1970-2010

(000)

Region	1970	1980	2010
	High		
I - Southern Md.	31	42	118
II - Western Md.	97	114	238
III - Baltimore Metro.	822	1,056	2,015
IV - Washington Metro.	319	452	1,007
V - Eastern Shore	103	129	236
Maryland	1,372	1,793	3,614
	Medium		
I - Southern Md.	30	39	88
II - Western Md.	93	104	176
III - Baltimore Metro.	786	950	1,488
IV - Washington Metro.	304	403	723
V - Eastern Shore	99	116	179
Maryland	1,313	1,613	2,654
	Low		
I - Southern Md.	30	37	69
II - Western Md.	90	97	133
III - Baltimore Metro.	758	871	1,123
IV - Washington Metro.	294	368	522
V - Eastern Shore	95	106	131
Maryland	1,267	1,479	1,978

TABLE 4

Projections of Total Employment by Place of Residence For Maryland and Sub-Regions, Actual 1960; Projected 1970-2010

(000)

Region	1960	1970	1980	2010
		High		
I - Southern Md.	24	35	49	133
II - Western Md.	92	103	124	253
III - Baltimore Metro.	668	822	1,056	2,015
IV - Washington Metro.	261	397	541	1,153
V - Eastern Shore	89	103	129	236
Maryland	1,134	1,460	1,899	3,790
		Medium		
I - Southern Md.	24	33	44	98
II - Western Md.	92	98	112	186
III - Baltimore Metro.	668	786	950	1,488
IV - Washington Metro.	261	379	486	849
V - Eastern Shore	89	99	116	174
Maryland	1,134	1,395	1,708	2,795
		Low		
I - Southern Md.	24	32	40	74
II - Western Md.	92	94	103	141
III - Baltimore Metro.	668	758	871	1,123
IV - Washington Metro.	261	366	446	642
V - Eastern Shore	89	95	106	131
Maryland	1,134	1,345	1,566	2,111

TABLE 5

Unemployment Rates, Maryland Sub-Regions, Actual 1960; Projected 1970-2010 (Percent of Labor Force)

Region	1960	1970	1980	1990	2000	2010
I - Southern Md.	4.0	4.0	4.0	4.0	4.0	4.0
II - Western Md.	7.0	6.0	5.0	4.0	4.0	4.0
III - Baltimore Metro.	5.3	4.9	4.4	4.0	4.0	4.0
IV - Washington Metro.	1.8	2.5	3.2	4.0	4.0	4.0
V - Eastern Shore	7.4	6.3	5.2	4.0	4.0	4.0

TABLE 6

Labor Force Participation Rates, Maryland Sub-Regions, Actual 1960; Projected 1970-2010

Region	1960	1970	1980	2010
I - Southern Md.	.287	.309	.332	.389
II - Western Md.	.369	.369	.381	.391
III - Baltimore Metro.	.391	.391	.390	.388
IV - Washington Metro.	.380	.379	.380	.383
V - Eastern Shore	.393	.389	.390	.390

Note: Labor force participation is the ratio of employment plus unemployment to population.

TABLE 7

Shares of Total Maryland Employment in Sub-Regions, Actual 1960; Projected 1970-2010 (Place of Employment)

Region	1960	1970	1980	2010
I - Southern Md.	2.2%	2.2%	2.3%	3.2%
II - Western Md.	8.7	7.0	6.3	6.5
III - Baltimore Metro.	62.6	59.9	58.8	55.7
IV - Washington Metro.	18.0	23.2	25.2	27.8
V - Eastern Shore	8.3	7.5	7.1	6.5

TABLE 8

Shares of Total Maryland Employment in Sub-Regions, Actual 1960; Projected 1970-2010 (Place of Residence)

Region	1960	1970	1980	2010
I - Southern Md.	2.1%	2.3%	2.6%	3.5%
II - Western Md.	8.1	7.0	6.5	6.6
III - Baltimore Metro.	58.9	56.3	55.6	53.1
IV - Washington Metro.	23.0	27.1	28.4	30.4
V - Eastern Shore	7.8	7.0	6.9	6.2

Note: Proportions are same for high, medium, and low projections.

TABLE 9

Percentage Composition of Employment, Maryland, 1960-2010 (Place of Employment)

	1960	1970	1980	2010
Agriculture and forestry	4.4%	2.8%	2.1%	1.2%
Mining	0.2	0.1	0.1	0.03
Contract construction	7.8	8.2	7.9	6.4
Manufacturing	24.3	23.1	21.6	17.8
Transportation, utilities	7.8	7.5	6.7	4.5
Trade	20.7	20.8	22.2	26.2
Finance, insurance, real estate	4.6	4.8	4.7	3.6
Services	19.1	20.6	22.7	27.9
Government	11.0	11.9	11.9	12.4

project that the percent of Maryland employment in manufacturing will fall from 24.3 in 1960 to 17.8 in 2010. The percentage of employment in trade, services and government is expected to grow gradually during the coming decades.

The final step in the employment projections was to break the manufacturing employment figures down into the twenty, two-digit manufacturing industries in the Standard Industrial Classification. This is a laborious procedure and has therefore been carried out only for the medium projections of employment by place of employment. The steps are as follows:

1. Compute two sets of ratios for the State of Maryland: (a) The percent which the State's employment in each two-digit industry represents of employment in that industry in the nation as a whole. Census data were employed for 1950 and 1960 and NPA data for 1976, and to some extent for 2000. (b) The ratio which employment in each two-digit industry comprises of total manufacturing employment in the State for 1950, 1960, and from NPA data for 1976.
2. Each of these sets of ratios was projected to the year 2010 by a combination of extrapolation of past trends and application of judgment. Multiplication of each set of projected ratios by the already projected manufacturing employment for the State in 2010 resulted in two independent sets of estimates of two-digit employment for the State in 2010. These two separate estimates were then reconciled by judgment into a single estimate, resulting in slight revisions of the extrapolated ratios.
3. Two sets of ratios were then computed for each region of the State for 1950 and 1960. These were (a) the ratio of each region's

employment in each two-digit industry to State employment in the same two-digit industry, and (b) the ratio of employment in each two-digit industry within each region to total manufacturing employment in the same region.

4. Once again, both of these sets of ratios were projected by judgment, but based on the 1950-60 trend.
5. Next, each set of projected ratios was applied to previously projected regional manufacturing employment to derive independent projections for 2010 of two-digit employment within regions. In this case, the reconciliation of the two independent estimates was done by an iterative process by which row totals and column totals were successively used to adjust figures. Judgment was applied at points where major changes had to be made.
6. By linear interpolation between the percent which each two-digit industry formed of total regional manufacturing employment in 2010, and the similar percent for 1960, the percentage composition of manufacturing employment within each region in 1970 and 1980 was derived. These resulting percentage distributions were then applied to previously projected total regional manufacturing employment in 1970 and 1980 to yield two-digit manufacturing employment in those two years.

The final two-digit employment projections are presented in Tables 10, 11, 12, and 13.

TABLE 10

Employment in Maryland by 2-Digit Manufacturing Industry

1970-2010 (At Place of Employment)

(000)

Medium Projection

S.I.C. No.	Industry	1970	1980	2010
20	Food and kindred products	43.1	45.9	50.6
21	Tobacco manufactures	0.1	0.1	0.1
22	Textile-mill products	5.3	5.2	4.1
23	Apparel	21.3	23.2	26.1
24	Lumber and wood products	6.4	7.2	8.0
25	Furniture and fixtures	6.5	7.5	10.2
26	Paper and allied products	9.6	11.2	17.4
27	Printing and publishing	16.6	19.5	27.2
28	Chemicals	23.6	25.5	29.1
29	Petroleum and coal products	1.5	1.7	2.6
30	Rubber products	10.2	11.8	16.3
31	Leather products	2.6	2.5	2.2
32	Stone, clay and glass	11.5	12.7	15.2
33	Primary metals	40.2	43.2	44.3
34	Fabricated metals	16.2	18.9	26.4
35	Non-electric machinery	13.8	15.4	18.7
36	Electric machinery	20.5	30.1	64.4
37	Transportation equipment	44.4	53.9	84.4
38	Instruments	3.7	5.9	13.0
39	Miscellaneous	7.5	7.5	15.5
	Total manufacturing	304.6	348.9	475.8

TABLE 11

Employment by 2-Digit Manufacturing Industry

Maryland Sub-Regions, 1970

(000)

Medium Projection

S.I.C. No.	Industry	Regions I	II	III	IV	V
20	Food and kindred products	1.4	2.2	23.3	2.7	13.5
21	Tobacco manufactures	-	-	0.1	-	-
22	Textile-mill products	-	3.2	1.9	-	0.2
23	Apparel	-	2.4	17.6	0.1	1.2
24	Lumber and wood products	1.1	0.6	2.0	0.6	2.1
25	Furniture and fixtures	-	0.5	5.4	0.6	0.1
26	Paper and allied products	-	2.2	6.8	0.4	0.2
27	Printing and publishing	0.1	1.0	11.8	2.8	0.8
28	Chemicals	0.1	0.5	17.6	3.3	2.1
29	Petroleum and coal products	0.1	0.1	1.0	0.3	-
30	Rubber products	-	2.4	7.1	0.4	0.4
31	Leather products	-	0.9	1.7	-	-
32	Stone, clay and glass	0.2	2.1	6.7	2.2	0.3
33	Primary metals	-	0.2	39.8	0.1	0.1
34	Fabricated metals	-	0.6	13.4	1.4	0.8
35	Non-electric machinery	-	1.2	10.3	1.6	0.8
36	Electric machinery	-	1.0	11.3	7.6	0.6
37	Transportation equipment	0.5	4.0	33.5	4.1	2.3
38	Instruments	-	0.6	1.9	1.2	0.1
39	Miscellaneous	-	1.2	5.5	0.1	0.7
	Total Manufacturing	3.6	25.8	218.7	29.5	26.2

TABLE 12

Employment by 2-Digit Manufacturing Industry

Maryland Sub-Regions, 1980

(000)

Medium Projection

S.I.C. No.	Industry	Regions I	II	III	IV	V
20	Food and kindred products	1.7	2.3	24.3	3.0	14.6
21	Tobacco manufactures	-	-	0.1	-	-
22	Textile-mill products	-	3.1	1.9	-	0.2
23	Apparel	-	2.4	19.2	0.2	1.4
24	Lumber and wood products	1.4	0.6	2.1	0.7	2.4
25	Furniture and fixtures	-	0.6	6.1	0.7	0.1
26	Paper and allied products	-	2.4	8.1	0.5	0.2
27	Printing and publishing	0.1	1.0	13.2	4.0	1.2
28	Chemicals	0.2	0.8	18.5	3.5	2.5
29	Petroleum and coal products	0.1	0.1	1.2	0.3	-
30	Rubber products	-	2.4	8.3	0.5	0.6
31	Leather products	-	0.9	1.5	-	0.1
32	Stone, clay and glass	0.2	2.1	7.4	2.6	0.4
33	Primary metals	-	0.2	42.8	0.1	0.1
34	Fabricated metals	-	0.7	15.3	1.9	1.0
35	Non-electric machinery	-	1.2	11.5	1.8	0.9
36	Electric machinery	0.1	1.3	16.5	11.0	1.2
37	Transportation equipment	0.7	4.3	41.1	5.2	2.6
38	Instruments	0.1	0.8	2.8	2.1	0.1
39	Miscellaneous	0.1	1.7	4.6	0.1	1.0
	Total Manufacturing	4.7	28.4	246.7	38.2	30.6

TABLE 13

Employment by 2-Digit Manufacturing Industry

Maryland Sub-Regions, 2010

(000)

Medium Projection

S.I.C. No.	Industry	Regions I	II	III	IV	V
20	Food and kindred products	2.6	3.1	25.0	3.2	16.7
21	Tobacco manufactures	-	-	0.1	-	-
22	Textile-mill products	-	2.6	1.3	-	0.2
23	Apparel	-	2.6	20.7	0.8	2.0
24	Lumber and wood products	1.8	0.6	2.1	0.7	2.8
25	Furniture and fixtures	0.2	0.8	8.0	1.0	0.2
26	Paper and allied products	0.1	3.7	12.3	0.9	0.4
27	Printing and publishing	0.4	1.4	17.8	5.6	2.0
28	Chemicals	0.2	0.9	21.7	3.5	2.8
29	Petroleum and coal products	0.2	0.2	1.6	0.5	0.1
30	Rubber products	0.1	3.1	11.1	1.1	0.9
31	Leather products	-	0.9	1.2	-	0.1
32	Stone, clay and glass	0.3	2.4	8.8	3.2	0.5
33	Primary metals	-	0.2	43.9	0.1	0.1
34	Fabricated metals	0.2	1.0	20.9	2.7	1.6
35	Non-electric machinery	-	1.6	13.8	2.0	1.3
36	Electric machinery	0.3	2.7	35.8	22.8	2.8
37	Transportation equipment	1.4	6.9	62.4	7.7	6.0
38	Instruments	0.4	1.6	6.3	4.5	0.2
39	Miscellaneous	0.5	3.1	9.2	0.3	2.4
	Total Manufacturing	8.6	39.0	323.4	60.6	42.2

CHAPTER III

HOUSEHOLD, COMMERCIAL, MUNICIPAL AND INSTITUTIONAL WATER USE

A. Introduction

This chapter presents an analysis and projections of water demand for household and closely-related commercial, municipal and industrial uses. In Maryland, approximately 85 percent of the population is served by municipal water supply systems, and the data in this chapter cover only water withdrawn by municipal systems. The part of the population not served by municipal systems is supplied by individual wells. This small minority is excluded from the calculations for three reasons. First, the amount withdrawn from individual wells is almost negligible in comparison with overall regional uses and will gradually become even less important as a larger percentage of the population is served by municipal systems. Second, most individual wells not only use ground water as a source but also return the water to the ground through septic tanks, and this neither adds to nor subtracts from surface water supplies in measurable quantity. Third, commercial, municipal and institutional uses are most closely related to that part of household use that is supplied by municipal systems.

Of course, many municipal systems obtain at least part of their water from wells, especially in Southern Maryland and on the Eastern Shore. These systems mostly discharge their effluent into surface water bodies and are included in the data presented in this chapter.

The demands for municipally supplied water can be classified according to household, commercial, municipal, institutional and industrial users. Municipal uses include fire protection, schools, government offices and institutions, parks, etc. Institutional uses include country clubs, private schools and colleges, some hospitals, etc. Although there are a few users that are hard to fit into this classification, the categories are much more precise than the available data.

It is reasonable to assume that commercial, municipal and institutional uses will vary closely with population and household uses. Many commercial uses, such as those in restaurants, laundries, etc., are close substitutes for similar household uses. Thus, the sum of household and commercial uses should display a more stable pattern than either of the components. Likewise, there is good reason to expect many institutional and municipal uses to depend mainly on the population served by the municipal system. These notions could be tested if adequate data were available showing breakdowns of municipal water use by households, industrial and other (i.e., commercial, institutional and municipal) uses. Unfortunately, there are almost no reliable published data of the required kind. For the Baltimore Region, we have been able to make some estimates of our own of water use by households and by industry. Hence, by subtraction from the known total of all uses, we can estimate the sum of commercial, institutional and municipal uses. We are forced to rely heavily on these estimates in our projections.

Industrial water use is a large part of total water use, but a small part of municipal water use. Chapter IV is devoted to industrial demand for water from both municipal and other sources. It is important to separate industrial from other uses of water supplied by municipal systems because industrial water use is closely related to a detailed classification of employment whereas other uses are closely related to population.

There has been a gradual rise in per capita use of water in households during recent years, both in Maryland and in the country as a whole. Part of the study was, therefore, directed to estimating the effects of various determinants of household water use in order to assist in projecting its future trend. It is probable that the major determinants of household water use are income, price of water, lot size, summer temperature and precipitation, and the presence in the household of water-using appliances (in which can be included backyard swimming pools). By careful analysis of water use data from a variety of cities and of the excellent data published by the Baltimore Bureau of Water Supply, it has been possible to estimate the effects of some of these factors. Summer temperature and precipitation show negligible trends within an area such as Maryland and can be ignored for our purposes. Household water use appears to be very unresponsive to the price of water, although estimation is made difficult by the infrequency of price changes. It is inevitable, however, that a sufficiently large increase in the price of water would result in a substantial decrease in demand. Therefore, the projections presented below are based on the implicit assumption that there will be no major increase in the price of water relative to the general price level. The historical increase in per capita water use seems to be mainly the result of rising incomes, the postwar suburbanization (which has increased the use of water for lawn sprinkling) and the spread of water-using appliances. Since all three of these factors are likely to continue in the foreseeable future, we project that the upward trend in per capita water use will continue. Table 1 presents an estimate of household water use per person served by municipal water systems in Maryland in 1960, and projections of that figure for the coming decades.

TABLE 1

Household Water Use per Person Served by Municipal Systems

	Gallons Per Capita Per Day
1960	63.4
1970	66.2
1980	74.4
2010	104.2

B. Withdrawal projections

In order to estimate and project withdrawals by municipal water supply systems for household, commercial and municipal purposes, several steps are necessary.

First, we must estimate and project the population served by municipal systems throughout the State. From unpublished data collected by the Public Health Service, we can estimate the population served in 1960 by municipal systems in each of the five sub-regions. These estimates indicate that 86.6 percent of the population was served by municipal systems in 1960, although the percentage varies greatly from region to region. This percentage has been rising gradually and will undoubtedly continue to do so in the coming decades. Estimates of population served in 1960 and projections for the future are shown in Table 2.

These figures indicate a gradual rise in the percentage of the population served by municipal systems to 89.3 percent in 1970, 91.4 percent in 1980, and 97.3 percent in 2010. The largest increases in the percentage of the population served by municipal systems are projected to occur in the

TABLE 2

Population Served by Municipal Water Supply Systems
(000) Medium Projections

	1960	1970	1980	2010
Maryland	2,687	3,393	4,227	7,251
Reg. I - Southern Md.	33	51	76	210
Reg. II - Western Md.	177	200	236	447
Reg. III - Baltimore Metro.	1,569	1,881	2,313	3,888
Reg. IV - Washington Metro.	698	1,023	1,320	2,265
Reg. V - Eastern Shore	210	238	282	441

regions in which that percentage was smallest in 1960. The result will be a gradual lessening of interregional differences in the percent of the population served by municipal systems during the coming decades.

Second, estimates must be made of commercial, municipal and institutional demands. For the Baltimore water supply system, the sum of these uses can be estimated quite accurately. We estimate total household uses by multiplying the 1960 per capita figure in Table 1 by the known total population served by the system. (The relevant figure is 1,397 thousand people. The figure given for Region III, 1960, in Table 2, 1,569 thousand people, includes those supplied by the municipal systems in Region III.) We have estimated demands by industry from unpublished data collected by the Public Health Service. Municipal, commercial and institutional uses can then be estimated by subtraction from the known total output of the system. The figures are given in Table 3.

TABLE 3

Demands by Major Water Users,
Baltimore Municipal System, 1960

	Million Gallons per Day
Households	88
Industry	40
Municipal, commercial, institutional	84
TOTAL	212

Thus it appears that the sum of municipal, commercial and institutional uses is about the same as household use. A conservative procedure would be to project these uses to grow at the same rate as population. The procedure we have adopted is to assume that these uses will grow at the same rate as household water demand. In other words, we project that the sum of municipal, commercial and institutional demands from municipal water supply systems will be about equal to household demands during the coming decades. This appears reasonable since, in many cases, the factors that cause increases in per capita water use in households will also cause similar increases in per capita water use in closely related commercial, municipal and institutional uses.

Third, we must estimate the seasonal component of water demand from municipal systems. As was pointed out in Chapter I, streamflow varies greatly from season to season. Most major demands also vary seasonably and, furthermore, periods of high demand tend to coincide with periods of low flow. Although the relevant concept of supply is complicated and is discussed at length in Chapter IX, it is clear that the relevant demands are those that occur during periods of low flow, usually during the summer months. Therefore, for each major water-using sector we will average daily demands over the four summer months of June, July, August and September rather than over the year as a whole. This means that projections of annual total demands cannot be obtained by multiplying our projections of daily total demand by 365. For the years 1940 to 1961, the average daily demand in the Baltimore municipal system was about 7 percent higher during the summer months than during the year as a whole. Therefore, our estimates of daily demand in this Chapter have been adjusted upward by this amount.

Fourth, the recorded withdrawal figures are those registered at filtration plants. These figures must be adjusted upward to allow for losses from the system between the point of withdrawal and the filtration plant. Although there are almost no available data, a frequently quoted figure is 15 percent, and we have used that figure throughout.

Fifth, and finally, the foregoing has referred to our medium projections. We have made high and low projections in exactly the same manner, except that the entire procedure has been applied to high and low population projections in Chapter II.

The estimates and projections are presented in Table 4.

Table 4 shows that total withdrawals by municipal water supply systems for all non-industrial purposes were about 422 m.g.d. during the summer months of 1960. Of this total, about 58 percent was in the Baltimore Region and about 27 percent was in the Washington, D.C. Region, or about 85 percent of the State total in the two metropolitan areas. Our medium projection

TABLE 4

Household, Commercial, Institutional, Municipal Demands For Water From Municipal Water Supply Systems, 1960-2010

(000 Gallons Per Day)

Region	1960	1970	1980	2010
		High		
I - Southern Md.	5,328	9,089	14,887	75,769
II - Western Md.	24,034	32,017	38,705	135,588
III - Baltimore Metro.	245,662	322,427	441,353	1,385,911
IV - Washington Metro.	112,831	180,818	258,520	817,506
V - Eastern Shore	33,954	41,946	59,654	210,096
Maryland	421,809	586,297	813,119	2,624,870
		Medium		
I - Southern Md.	5,328	8,619	14,417	55,789
II - Western Md.	24,034	30,526	37,587	99,691
III - Baltimore Metro.	245,662	306,886	427,380	1,018,269
IV - Washington Metro.	112,831	172,538	250,319	601,559
V - Eastern Shore	33,954	40,170	53,490	117,115
Maryland	421,809	558,739	783,193	1,892,423
		Low		
I - Southern Md.	5,328	8,306	13,268	42,338
II - Western Md.	24,034	29,429	34,539	75,766
III - Baltimore Metro.	245,662	296,413	390,415	766,305
IV - Washington Metro.	112,831	166,661	229,790	454,773
V - Eastern Shore	33,954	38,681	49,207	88,541
Maryland	421,809	539,490	717,219	1,427,723

implies that total withdrawals in 2010 will be about 4.5 times the 1960 total. Approximately 54 percent of the 2010 total will be demanded in the Baltimore Region and about 32 percent in the Washington, D.C. Region, or 86 percent of the State total for the two metropolitan areas.

C. Consumption

The final task in this chapter is to estimate the part of the withdrawals shown in Table 4 that will be consumed in use. It was stated in Chapter I that the relevant definition of consumption for our purposes is any use that makes the water unavailable for further use. In particular, it was stated that discharge into saline bodies is to be considered a consumptive use. Since almost all the municipal water supply systems in Maryland are located on or near tidal waters, it must be expected that most municipal withdrawals will be consumptive.

In Regions I (Southern Maryland), IV (Washington, D.C. area) and V (Eastern Shore), we have assumed in our calculations that all municipal withdrawals are consumptive. In these Regions, almost all the communities served by municipal systems are located on or near tidal estuaries of rivers or reaches of the Chesapeake Bay. Most of these municipal systems discharge their effluent into brackish waters. So far as is known, there is at present no industrial reuse of effluent in these Regions. In most cases, these conditions seem likely to continue in the foreseeable future. The one area in which industrial reuse of municipal effluent seems a likely possibility is in the Washington, D.C. Region. Although we know of no present plans to reuse effluent in the Washington area, municipal effluent is now reused extensively in Baltimore and elsewhere. If projections of substantial industrial growth in the Washington Region turn out to be correct, reuse of effluent may become feasible. Thus, ignoring this possibility in our calculations may introduce an upward bias in our projections of consumptive uses.

In Region III (Baltimore area) it is assumed that all municipal withdrawals are consumptive except for the effluent of the Baltimore water supply system that is reused by industry. In 1960, about 100 m.g.d. of Baltimore's effluent was reused by industry. In our calculations, we assume that the amount reused will increase in the following way:

1960	100	m.g.d.
1970	130	m.g.d.
1980	140	m.g.d.
2010	180	m.g.d.

Thus, for the Baltimore Region, our projection of consumption is the projection of withdrawal minus the above amounts. These amounts were subtracted from all three projections for each year.

In Region II (Western Maryland), there are no discharges into saline bodies. Therefore, the amount of water consumed in this region is the difference between the amount withdrawn and the amount of effluent discharged. This difference results partly from leakages in the systems and partly from consumptive uses of water obtained from the municipal system. Consumptive uses of industrial withdrawals from both municipal and other sources will be considered in the next chapter. Of the non-industrial withdrawals from municipal systems included in Table 4, consumption results mainly from such uses as lawn watering, evaporation and splash-out from swimming pools, irrigation of nurseries, etc. A figure of 15 percent for leakages between the point of withdrawal and the point of metering has already been incorporated in the withdrawal figures in Table 4. Little is known of the magnitude of further leakages and the consumptive uses indicated above, but 10 percent seems to be a reasonable guess. Therefore, the sum of the two figures, or 25 percent of withdrawals, has been used to project consumption in Region II. That percentage has been assumed for all three projections in each year.

The resulting projections of consumption are presented in Table 5. Comparison between Tables 4 and 5 indicates that in 1960 about 72 percent of the withdrawals by municipal systems in Maryland for non-industrial purposes were consumptive. The medium projections imply that this percentage will rise gradually to 87 percent by 2010. Thus, although withdrawals in 2010 will be about 4.5 times their 1960 volume, consumption will be about 5.4 times its 1960 volume. These results follow from our projections that population will be increasingly concentrated in those parts of the State that border on tidal waters.

TABLE 5

Household, Commercial, Institutional, Municipal Consumption of Water From Municipal Water Supply Systems, 1960-2010

(000 Gallons Per Day)

Region	1960	1970	1980	2010
High				
I - Southern Md.	5,328	9,089	14,887	75,769
II - Western Md.	6,793	9,048	10,939	38,320
III - Baltimore Metro.	145,662	192,427	301,353	1,205,911
IV - Washington Metro.	112,831	180,818	258,520	817,506
V - Eastern Shore	33,954	41,946	59,654	210,096
Maryland	304,568	433,328	645,353	2,347,602
Medium				
I - Southern Md.	5,328	8,619	14,417	55,789
II - Western Md.	6,793	8,627	10,623	28,174
III - Baltimore Metro.	145,662	176,886	287,380	838,269
IV - Washington Metro.	112,831	172,538	250,319	601,559
V - Eastern Shore	33,954	40,170	53,490	117,115
Maryland	304,568	406,840	616,229	1,640,906
Low				
I - Southern Md.	5,328	8,306	13,268	42,338
II - Western Md.	6,793	8,317	9,761	21,413
III - Baltimore Metro.	145,662	166,413	251,415	586,305
IV - Washington Metro.	112,831	166,661	229,790	454,773
V - Eastern Shore	33,954	38,681	49,207	88,541
Maryland	304,568	388,378	553,441	1,193,370

CHAPTER IV

INDUSTRIAL WATER USE

A. Introduction

The purpose of this chapter is to present the analysis and projections of industrial water use. Industrial withdrawals are by far the largest of the four major water-using sectors considered in Chapters III-VI of this report. Two factors make the analysis of industrial water use more complicated than the municipal uses analyzed in the previous chapter. First, most of the largest industrial withdrawals are not from municipal systems. This makes the problem of data collection more difficult. Second, a large part of the industrial withdrawals in Maryland are from brackish bodies of water. As pure, fresh water becomes scarcer, the availability of vast quantities of brackish water becomes a more important attraction to industry. The result is that industrial withdrawals of brackish water have increased rapidly in recent years, and are likely to increase rapidly in the foreseeable future. It is, in consequence, both desirable and inevitable that a large part of the following analysis should include the use of brackish water by industry. The main focus of the report is on fresh water use, however, and it is therefore necessary to distinguish between fresh and brackish water to the extent that the data will allow.

Water, along with various kinds of labor, capital and other natural resources, is an input in many industrial processes. There is great variety in the uses to which water is put in industry, and the relevant technological and economic considerations differ from use to use. A frequent classification of industrial uses of water distinguishes between sanitary, process, cooling and boiler feed uses.

For each of these uses there are three major dimensions: quantity withdrawn, quantity consumed, and change in quality resulting from use. We will follow the procedure adopted in the previous chapter of first estimating and projecting withdrawals and then estimating the portion of withdrawals that will be consumptive. Waste discharges by industry, as well as by other users, will be considered in Chapter VII.

A pervasive characteristic of modern industry is that there are many ways of producing almost any product, and usually, the proportions in which inputs are used will vary considerably from one method of production to another. This is no less true of water inputs in any of the three dimensions indicated above. A substantial increase in the price and scarcity of water relative to other inputs will lead firms to economize on the use of water and to substitute low quality water for high quality water. It is almost inevitable that pure water will become more expensive, relative to other inputs in the future, than it has been in the past. On this basis we are justified in projecting that other inputs will be substituted for water to a modest degree. However, our procedure in this chapter (as in chapters on other withdrawal uses) is to assume no substantial increases in water costs or scarcity, to add up all demands projected in this assumption, and to compare demands with potentially available supplies. If the demands do not exceed the supplies, we will then be justified in our assumption that water prices will not rise substantially. If the demands projected on this assumption should exceed supplies, we would have to adjust demand projections downward to allow for economizing as a result of increasing costs and scarcity of water.

There is another major factor that affects the trends of industrial input use. As technology improves, there is a tendency for industry to increase the amount of output that it can produce with given amounts of inputs. Although increases in output per unit of input do not proceed uniformly with all inputs, they are observed in all major classes of capital, labor and natural resource inputs.[1] Although very little evidence is available, it is reasonable to assume that the improvement in technology has affected economies in water use as well as in other inputs in industry and that the trend will continue in the future.[2]

The available evidence on industrial water withdrawals is presented in Section B. In Section C, estimates and projections for Maryland are presented. In Section D, industrial water consumption projections are derived from the projections of withdrawals. Finally, Section E considers water use for thermal electric generation.

B. A survey of the evidence

The only available comprehensive data on industrial water use come from the Censuses of Manufactures in 1954 and 1959.[3] 1954 was the first time that water use data were included in the Census, and the effort was continued and expanded in 1959. Data on quality were not collected, and data on consumption are unreliable because of rounding errors, particularly at the state level. Therefore, attention is focused on withdrawals in this section. Both withdrawals and consumption tend to be concentrated in a small number of two-

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1. Productivity Trends in the United States, John Kendrick, National Bureau of Economic Research, Princeton University Press, 1961.

2. Although no comprehensive indices are presented, the best discussion of this question is Technology in American Water Development, Ackerman and Löf, Johns Hopkins Press, 1959.

3. A recent cooperative survey of industrial water use was completed too late to be included in the text. It is analyzed in the Appendix to this chapter.

digit industries and in a small number of four-digit industries within those two-digit industries. Two-digit industries, e.g., food processing (20) and chemicals (28) are broad, inclusive classes and it is therefore preferable to undertake analysis at the relatively homogeneous four-digit level, e.g., paper mills (2621), hydraulic cement (3241). However, no State data, and only limited regional data, are available at the four-digit level in the two Censuses. Furthermore, our employment projections, to which water use projections must be tied, were necessarily at the two-digit level. Therefore, much of the analysis must be at the two-digit level.

Table 1 presents relevant national totals for the major two- and four-digit water-using industries for 1954 and 1959. The value added figures in the first column have been adjusted for price level changes, so that both the 1954 and the 1959 figures are expressed in constant 1959 prices.

Consider first the data for the two-digit industries: The typical pattern displayed by these is a substantial rise in output (value added), but a small rise or even a decline in employment, water intake and water consumption. The columns showing intake per dollar of value added, and consumption per dollar of value added, typically show substantial decreases over the five-year interval from 1954 to 1959. The final column in the table shows the annual percentage rate of growth of output per unit of water intake from 1954 to 1959. These figures vary from -2.5 percent (machinery) to 5.5 percent (stone, clay, glass products), with an average of 1.25 percent. This means that on the average these industries produced 1.25 percent more output per gallon of water withdrawn each year than they did the previous year.

Now, this growth of output per unit of input can be the result of only two factors. One possibility is that output has shifted away from heavy

TABLE 1

Value Added, Employees, Water Use, U.S., 1954, 1959

Industry	Value added (000 '59 $/day)		Employees (thousands)		Intake (m.g.d.)		Discharge (m.g.d.)		Consumption (m.g.d.)	
	1954	1959	1954	1959	1954	1959	1954	1959	1954	1959
20 Food	18,068	22,219	672	618	1,688	1,710	1,507	1,565	181	145
26 Paper	8,193	10,522	251	282	4,894	5,307	4,439	4,998	455	310
28 Chem.	18,073	26,707	447	434	7,357	8,878	6,987	8,387	370	490
29 Pet., coal	5,491	6,850	155	142	3,411	3,614	3,107	3,299	304	315
32 Stone, clay, glass	6,077	8,442	207	231	764	808	696	734	68	74
33 Prim. metals	29,255	29,313	912	852	10,527	10,143	10,089	9,730	438	414
34 Fab. metals	8,609	8,957	358	316	310	121	279	112	30	8
35 & 36 Machinery	31,981	32,365	1,154	1,081	625	723	564	693	60	30
37 Trans. eqmt.	38,223	39,840	1,418	1,285	633	712	589	627	44	85
Total	163,970	185,215	5,574	5,241	30,209	32,016	28,257	30,145	1,950	1,871
2621 Paper mills	-	4,811	-	128.7	-	2,984	-	2,803	-	181
2818 Organic chem.	3,244	4,946	63.8	70.4	2,570	3,899	2,488	3,778	82	121
2911 Petroleum	4,943	6,554	143.2	134.8	3,348	3,592	3,050	3,285	299	307
3241 Cement	1,493	1,970	33.8	36.6	501	490	422	438	79	52
3312 Steel mills	17,465	17,952	537.6	496.5	8,636	8,204	8,302	7,880	334	323
3711 Motor vehicles	18,353	21,265	582.8	517.4	249	342	236	323	14	19
Total	45,498	57,498	1,361.2	1,384.4	15,304	19,511	14,498	18,507	808	823

(continued on next page)

TABLE 1

Value Added, Employees, Water Use, U.S., 1954, 1959

Industry	Intake/V.A. (g/$)		Intake/emp. (g/emp.)		Cons./V.A. (g/$)		Cons./emp. (g/emp.)		Annual % Growth in VA/intake
	1954	1959	1954	1959	1954	1959	1954	1959	
20 Food	93.4	77.0	917	1,010	10.00	6.54	98.21	85.76	4
26 Paper	597.3	504.4	7,116	6,869	55.52	29.43	661.35	400.71	3.5
28 Chem.	407.0	332.4	6,007	7,465	20.47	18.36	302.01	412.44	4
29 Pet., coal	621.2	527.6	8,032	9,289	55.39	46.00	716.13	809.86	3.5
32 Stone, clay, glass	125.7	95.7	1,348	1,277	11.27	8.76	120.77	116.88	5.5
33 Prim. metals	359.8	346.0	4,213	4,345	14.99	14.11	175.44	177.23	0.5
34 Fab. metals	36.0	13.5	316	139	3.50	0.92	30.73	9.49	20
35 & 36 Machinery	19.5	22.4	198	244	1.88	0.93	19.06	10.18	-2.5
37 Trans. eqmt.	16.6	17.9	163	202	1.15	2.13	11.28	24.12	-1.3
Total	184.2	172.7	1,978	2,228	11.89	10.10	187.70	130.30	1.25
2621 Paper mills	-	620.2	-	8,462	-	37.59	-	512.82	-
2818 Organic chem.	792.2	788.4	14,702	20,213	25.34	24.38	470.22	625.00	1
2911 Petroleum	677.4	548.1	8,534	9,726	60.42	46.82	761.17	830.86	4
3241 Cement	335.8	249.0	5,414	4,891	53.21	26.43	857.99	519.13	6
3312 Steel mills	494.5	457.0	5,859	6,036	19.14	18.01	226.77	237.90	1.3
3711 Motor vehicles	13.6	16.1	156	242	0.70	0.90	8.58	13.53	-0.3
Total (omits 2621)	336.4	313.7	4,104	4,920	17.70	15.60	216.80	244.70	1.25

Source: Census of Manufactures, 1954 and 1958.

water-using industries within two-digit categories. It will be shown below, however, that the same pattern of growth of output per gallon of water withdrawn has taken place in the heavy water-using four-digit industries, within which almost no such shifting is possible. Therefore, the major part of the growth in output per gallon of water withdrawn must have resulted from the second possibility, a widespread tendency to economize on the use of water in most heavy water-using industries.

Increases of output per unit of input of the magnitude indicated above for water are not implausible. For manufacturing as a whole, careful studies by Kendrick have shown that an index of output divided by an index of all inputs grows on the average by about 2 percent per year. This suggests that although there is a tendency to economize on the use of water, there is a tendency to economize even more on the use of other inputs, particularly labor. Output per employee typically grows more rapidly than output per unit of other inputs, since labor gradually becomes more expensive relative to other inputs as time passes. We should thus expect gradual decreases in water intake per unit of output as time passes, but gradual increases in water intake per employee. It can be seen from Table 1 that water intake per employee did, in fact, rise in most two-digit industries, and on the average.

Looking at the bottom of Table 1, it is apparent that these findings are confirmed at the four-digit level. In four of the five industries for which data are available for both years, output per gallon of intake rose from 1954 to 1959. The average for the five industries was 1.25 percent per year growth in output per gallon of water intake, the same figure observed at the two-digit level.

Thus, the national data in Table 1 suggest a mild but pervasive tendency to economize on the use of water through time. It is important to know whether this tendency is the result of improved technology, or of an increase in the cost, scarcity or rationing of water. Unfortunately, no relevant measure of the "cost" of water is available. Nevertheless, one would expect that, in a general way, the effect of differences in water cost would be evident in data on water use per unit of output in different regions. One would expect that water use per unit of output would be relatively low in water-scarce regions. An examination of the available regional data on industrial water use is therefore in order. For this purpose it is eminently practical to use four-digit data because, at the two-digit level, there is undoubtedly a tendency for those firms that produce water-intensive products to locate in areas of plentiful water. Thus, at the two-digit level, the observation that water intake per unit of output is low in water-scarce areas probably reflects differences in the products produced in different regions, rather than substitution of other inputs for water. This is much less true at the four-digit level. Unfortunately, no four-digit data are available by state, and we must therefore be content with data for the 18 major water regions. Furthermore, data for each of the six four-digit industries in Table 1 are available for only a few regions. Table 2 presents the available data, along with calculations similar to those in Table 1. Again, the 1954 value added data are expressed in 1959 prices.

Two things are particularly striking in Table 2: First is the large variation in intake per dollar of value added from one region to another. For most industries, the largest figure is three or four times the smallest. In most of the industries, there is an obvious tendency for ratios of intake to output to be higher in humid areas than in dry areas. In industry 2621

TABLE 2

Value Added, Employees, Water Use, Regions, 1954, 1959

	Value added (000 '59 $/day)		Employees (Thousands)		Intake (m.g.d.)		Discharge (m.g.d.)		Consumption (m.g.d.)	
	1954	1959	1954	1959	1954	1959	1954	1959	1954	1959
2621										
N. Eng.	-	1,058	-	27.1	-	507	-	433	-	74
Del. Hud.	-	301	-	8.5	-	307	-	301	-	5
Ches.	-	255	-	8.1	-	153	-	148	-	5
E. Gt. L.	-	260	-	9.9	-	173	-	164	-	8
Ohio	-	359	-	10.2	-	104	-	93	-	11
Tenn.	-	227	-	6.9	-	186	-	181	-	5
S.E.	-	589	-	12.3	-	515	-	507	-	8
W. Gt. L.	-	469	-	13.3	-	277	-	258	-	19
U. Miss.	-	403	-	12.8	-	214	-	203	-	11
A.W.R.	-	236	-	6.0	-	101	-	96	-	5
W. Gulf	-	162	-	3.8	-	63	-	52	-	11
Pac. N.W.	-	452	-	9.0	-	362	-	348	-	14
2818										
Del. Hud.	575	680	-	14.5	151	189	145	164	5	25
E. Gt. L.	175	167	-	2.6	77	58	74	58	3	0
Ohio	655	890	-	12.8	680	822	671	806	8	16
W. Gt. L.	85	400	-	7.1	60	197	58	189	3	8
L. Miss.	296	384	-	5.4	30	175	30	173	0	3
2911										
Del. Hud.	638	904	-	19.6	680	937	655	910	25	27
E. Gt. L.	263	348	-	4.8	162	186	145	173	16	14
Ohio	244	321	-	6.5	129	121	104	104	25	16
W. Gt. L.	441	496	-	11.1	373	449	362	436	11	14
U. Miss.	299	296	-	6.1	52	41	41	30	11	11
L. Miss.	282	362	-	-	181	269	173	258	8	11
Mo.	208	315	-	5.2	77	85	60	68	16	16
A.W.R.	529	819	-	12.1	77	88	30	38	47	49
W. Gulf	1,269	1,606	39.9	40.0	1,055	858	975	759	79	99
Cal.	633	869	16.6	16.5	433	411	378	370	55	41

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TABLE 2

Value Added, Employees, Water Use, Regions, 1954, 1959

	Value added (000 '59 $/day)		Employees (Thousands)		Intake (m.g.d.)		Discharge (m.g.d.)		Consumption (m.g.d.)	
	1954	1959	1954	1959	1954	1959	1954	1959	1954	1959
3241										
Del. Hud.	211	222	5.3	5.0	68	88	63	82	5	22
S.E.	-	175	-	3.0	-	41	-	22	-	19
W. Gt. L.	93	137	3.1	3.7	159	197	153	192	5	5
U. Miss.	178	181	4.1	3.1	134	55	132	52	3	3
3312										
Del. Hud.	1,110	1,400	43.5	38.2	575	575	551	543	25	33
E. Gt. L.	2,666	2,740	72.7	66.8	1,488	1,570	1,463	1,529	25	41
Ohio	6,803	6,902	223.8	199.9	3,277	2,992	3,159	2,891	118	101
S. E.	890	767	24.1	21.7	195	189	151	148	44	41
W. Gt. L.	2,935	2,765	84.5	76.8	2,143	1,902	2,115	1,888	27	14
U. Miss.	-	501	-	14.0	-	167	-	134	-	33
3711										
E. Gt. L.	7,982	8,694	293.8	229.5	121	244	115	236	5	8
W. Gt. L.	4,368	5,025	141.2	133.3	68	47	66	44	3	3

(continued on next page)

TABLE 2

Value Added, Employees, Water Use, Regions, 1954, 1959

	Intake/V.A. (G/$)		Intake/Emp. (G/Emp.)		Cons./V.A. (G/$)		Cons./Emp. (G/Emp.)	
	1954	1959	1954	1959	1954	1959	1954	1959
2621								
N. Eng.	-	479.3	-	6,827	-	69.95	-	996.31
Del. Hud.	-	1,018.2	-	13,176	-	18.18	-	235.29
Ches.	-	602.2	-	6,914	-	21.51	-	246.91
E. Gt. L.	-	663.2	-	6,364	-	31.58	-	303.03
Ohio	-	290.1	-	3,726	-	30.53	-	392.16
Tenn.	-	819.3	-	9,855	-	24.10	-	289.86
S. E.	-	874.4	-	15,285	-	13.95	-	243.90
W. Gt. L.	-	590.6	-	7,594	-	40.94	-	526.32
U. Miss.	-	530.6	-	6,094	-	27.21	-	312.50
A.W.R.	-	430.2	-	6,167	-	23.26	-	333.33
W. Gulf	-	389.8	-	6,053	-	67.80	-	1,052.63
Pac. N.W.	-	800.0	-	14,667	-	30.30	-	555.56
2818								
Del. Hud.	261.9	278.2	3,901	4,759	9.52	36.29	-	620.69
E. Gt. L.	437.5	344.3	5,714	8,077	15.63	0.00	-	0.00
Ohio	1,037.7	923.1	16,871	23,438	12.55	18.46	-	468.75
W. Gt. L.	709.7	493.2	9,167	10,141	32.26	20.55	-	422.54
L. Miss.	101.9	457.1	2,391	11,852	0.00	7.14	-	185.19
2911								
Del. Hud.	1,064.4	1,036.4	10,974	17,449	38.63	30.30	-	510.20
E. Gt. L.	614.6	535.4	10,350	14,167	62.50	39.37	-	1,041.67
Ohio	528.1	376.1	6,620	6,769	101.12	51.28	-	923.08
W. Gt. L.	844.7	906.1	10,303	14,775	24.84	27.62	-	450.45
U. Miss.	174.3	138.9	2,794	2,459	36.70	37.04	-	655.74
L. Miss.	640.8	742.4	8,250	-	29.13	30.30	-	-
Mo.	368.4	269.6	4,828	5,962	78.95	52.17	-	1,153.85
A.W.R.	145.1	107.0	2,074	2,645	88.08	60.20	-	1,487.60
W. Gulf	831.5	534.1	9,649	7,825	62.63	61.43	726.82	900.00
Cal.	684.0	473.2	9,518	9,091	86.58	47.32	1,204.82	909.09

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TABLE 2

Value Added, Employees, Water Use, Regions, 1954, 1959

	Intake/V.A. (G/$)		Intake/Emp. (G/Emp.)		Cons./V.A. (G/$)		Cons./Emp. (G/Emp.)	
	1954	1959	1954	1959	1954	1959	1954	1959
3241								
Del. Hud.	324.7	395.1	4,717	6,400	25.97	98.77	377.36	1,100.00
S.E.	-	234.4	-	5,000	-	109.38	-	2,333.33
W. Gt. L.	1,705.9	1,440.0	18,710	19,460	58.82	40.00	645.16	540.54
U. Miss.	753.8	303.0	11,951	6,452	15.38	15.15	243.90	322.58
3312								
Del. Hud.	518.5	411.0	4,828	5,497	22.22	23.48	206.90	314.14
E. Gt. L.	558.1	573.0	7,469	8,578	9.25	15.00	123.80	224.53
Ohio	481.7	433.5	5,344	5,463	17.32	14.69	192.14	185.09
S. E.	218.5	246.4	2,946	3,180	49.23	53.57	663.90	691.24
W. Gt. L.	730.2	687.8	9,254	9,036	9.34	4.96	118.34	65.10
U. Miss.	-	333.3	-	4,357	-	65.57	-	857.14
3711								
E. Gt. L.	15.1	28.0	150	388	0.69	0.95	6.81	13.07
W. Gt. L.	15.7	9.3	177	128	0.63	0.55	7.08	7.50

Source: Census of Manufactures, 1954, 1958. For the regional classification, see Census of Manufactures, 1958, Vol. 1, p. 11-6.

(paper mills), for example, the correlation between intake per dollar of value added and average precipitation for the region is +0.57. However, not a great deal can be made of this correlation. Precipitation is not a good measure of water cost or scarcity. Furthermore, there are many exceptions to the rule. Second, the tendency for intake per unit of output to decline between 1954 and 1959 is strong. But there are many exceptions to this rule, too. The most striking is the quadrupling of intake per unit of output in the organic chemical industry (2818) in the Lower Mississippi region.

It appears from the data in Tables 1 and 2 and from other evidence that the trend downward in water intake per unit of output is real and pervasive. This decline is unlikely to be the result of data inaccuracies, nor is it a temporary aberration. In fact, it appears to be mainly the result of a variety of technological improvements rather than the manifestation of increasing cost or scarcity of water. Therefore, the trend is likely to continue in the foreseeable future, and may even accelerate somewhat as industry becomes more conscious of water's value.

The projections presented in the next section all assume that intake per unit of output will fall gradually during the years covered by the tables. The projected trend differs from industry to industry depending on factors specific to each industry.

C. Withdrawal projections

Several steps are necessary in estimating and projecting water intake by Maryland industry on the basis of Census data. First, the projections must be stated in terms of intake per employee rather than intake per unit of output. This step is necessary because we must tie our projections of water intake to the employment projections presented in Chapter II. It can be seen from Tables 1 and 2 that, although intake per unit of output fell in most industries from 1954 to 1959, intake per employee rose in most industries. The reason for this is clear. Water and labor are both inputs. In a given period of time, both output per worker and output per gallon of water intake tend to rise. Intake per employee will rise through time if firms economize more on labor than on water. It was stated in the previous section that this has been the trend in the recent past. Whereas output per worker has risen about 2 percent per year in the average manufacturing industry, output per unit of water intake has risen by only about 1.25 percent on the average. Thus, intake per worker has risen on the average. Although there is great variability from industry to industry, the general trend of increasing intake per employee is likely to continue in the foreseeable future in most industries.

Second, the employment base must be altered to correspond to the employment projections. In Tables 1 and 2, the figures include only those firms whose intake is at least 20 million gallons per year. Although such firms include almost all the water intake in the respective industries, they include a much smaller fraction of all the employees in the industries. Since our projections are of total employees, we must express intake in terms of total employees to get comparable figures.

Third, we must try to discover how different the Maryland data are from national and regional data. Table 3 presents the relevant data. In this table the intake figures are those presented by the Census for major water-users. The employee figures, however, are totals for the industry rather than totals for the firms whose intakes are presented. The Maryland data are presented for all the industries whose figures are given by the Census.

TABLE 3

Intake per Employee, Maryland and U.S., 1959

Industry	Intake (m.g.d.)		Employees (000)		Intake per Emp. g/emp/day	
	Md.	U.S.	Md.	U.S.	Md.	U.S.
20 Food	36	1,710	35.8	1,762	995	970
26 Paper	-	5,307	8.9	578	-	9,182
28 Chem.	104	8,878	12.9	785	8,066	11,309
29 Pet., coal	-	3,614	1.3	245	-	14,751
32 Stone, clay, glass	11	808	8.5	576	1,292	1,403
33 Prim. metals	477	10,143	36.0	1,136	13,247	8,929
34 Fab. metals	3	121	14.5	1,089	189	111
36 Machinery	3	255	16.6	1,199	165	767
37 Trans. eqmt.	5	712	43.7	1,636	188	435

Source: Census of Manufactures, 1959.

It must be expected that the Maryland intake per employee figures will differ considerably from the national averages. This results partly from different relative prices of water and other inputs in Maryland as compared with the U.S. as a whole, and mostly, perhaps, from substantial differences in the product mix within two-digit industries between Maryland and the country as a whole.

On the basis of the analysis in Section B and the data in Table 3, we have projected intake per employee as shown in Table 4. Where available, the 1959 figures in Table 4 are taken from Table 3. Where the Maryland figure is unavailable, the U.S. figure is used. For the major water-using industries (20, 26, 28, 29, 32, 33, 34, 36, 37) an attempt was made to project future increases, if any, in intake per employee. These projections are intuitive, based on the data presented above, the projections made by the Kerr Committee,[4] and on other factors related to particular industries. For the remaining industries, the 1959 figure was assumed for the projection period.

Multiplying the intake per employee figures in Table 4 by employment levels will provide estimates of total water intake by industry. The required estimates and projections are, however, for fresh water intake. We must therefore estimate the portion of total withdrawals that is from fresh water sources. Relevant information available from the Census of Manufactures is summarized in Table 5. No State data on industrial water use are presented in the 1954 Census and the 32.7 percent refers to the Chesapeake area. According to the Census data, two-thirds of the industrial intake in Maryland and 20 percent in the country as a whole were brackish in 1959. The U.S.

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[4] See Kerr Committee Print No. 8.

TABLE 4

Maryland Industrial Water Intake per Employee, 1959 and Projections for 1970, 1980, 2010

Industry	1959	1970	1980	2010
20 Food	995	1,095	1,150	1,322
21 Tobacco	89*	89	89	89
22 Textiles	403*	403	403	403
23 Apparel	23*	23	23	23
24 Lumber	654*	654	654	654
25 Furniture	24*	24	24	24
26 Paper	9,182*	9,182	9,182	9,182
27 Printing	41*	41	41	41
28 Chemicals	8,066	9,680	11,615	16,508
29 Petroleum	14,751*	16,227	17,849	23,204
30 Rubber	1,037*	1,037	1,037	1,037
31 Leather	92*	92	92	92
32 Stone, clay, glass	1,292	1,292	1,292	1,292
33 Primary metals	13,247	13,578	13,917	15,309
34 Fab. metals	189	189	189	189
35 & 36 Machinery	101	111	122	146
37 Trans. eqmt.	188	226	248	323
38 Instruments	207*	207	207	207
39 Miscellaneous	66*	66	66	66
Total	2,929	3,278	3,284	3,249

* Indicates figure for U.S.

TABLE 5

Withdrawals of Brackish Water as Percent of Total Withdrawals, Chesapeake Area and U.S., 1954; Maryland and U.S., 1959

Industry	1954		1959	
	Chesapeake	U.S.	Maryland	U.S.
20 Food	-	10.2	46.2	11.1
28 Chemicals	-	18.3	47.4	35.7
30 Rubber	-	2.8	0.0	3.1
32 Stone, clay, glass	-	7.9	0.0	9.8
33 Prim. metals	-	6.1	83.3	7.9
34 Fab. metals	-	0.5	0.0	2.3
36 Machinery	-	9.3	0.0	11.8
37 Trans. eqmt.	-	3.6	33.3	21.5
Total	32.7	13.8	66.3	20.1

Source: Census of Manufactures, 1959.

figure grew rapidly from 1954 to 1959 and the evidence suggests that the same was true in Maryland. In our projections, the assumption is that the percent of withdrawals from brackish water will rise slightly in some industries, and will remain at its 1959 level in others.

From the data on intake per employee in Table 4, our employment projections in Chapter II, and the above projections of the percent brackish withdrawal, we obtain the estimates of total Maryland industrial withdrawals of fresh water presented in Table 6, and the projections shown in Tables 7, 8 and 9. (Comparison with data from the Census of Manufactures and with the Public Health Service data presented in the Appendix indicates that the 1960 totals in Table 6 are quite accurate.) The tables indicate that industrial intake of fresh water will increase by about one-third between 1960 and 1970, by about one-quarter between 1970 and 1980, and by nearly one-half between 1980 and 2010. It is remarkable how much the industrial use of water is concentrated in the Baltimore Region. In 1960, over 75 percent of all industrial withdrawals in the State were in the Baltimore Region. By 2010, we project that withdrawals in the Baltimore Region will still exceed two-thirds of all withdrawals in the State.

D. Consumption projections

This section estimates the portion of projected fresh water withdrawals by industry that will be consumptive. The definition of consumptive use and the procedures followed are basically those used in the previous chapter. As was true in the previous chapter, the major consumptive use of fresh water to be considered here is that which is discharged into brackish bodies. On the Eastern Shore, in Southern Maryland, and in the Baltimore Region virtually all industrial effluent is discharged either into estuaries or into municipal

TABLE 6

Maryland Industrial Fresh Water Intake Estimates, 1960

(000 gal. per day)

Industry	Regions Southern Md. I	 Western Md. II	 Baltimore Metro. III	 Washington Metro. IV	 Eastern Shore V	 Total
20 Food	433	3,253	17,935	1,422	8,686	31,729
21 Tobacco	-	-	8	-	-	8
22 Textiles	-	1,473	794	-	76	2,343
23 Apparel	-	52	361	-	19	432
24 Lumber	339	400	1,323	136	1,147	3,345
25 Furniture	-	10	117	5	-	132
26 Paper	-	20,326	52,191	1,128	1,394	75,039
27 Printing	-	41	430	41	27	539
28 Chemicals	-	1,079	46,943	5,953	3,895	57,870
29 Petroleum	-	339	14,161	1,328	-	15,828
30 Rubber	-	2,506	6,454	145	315	9,420
31 Leather	-	87	150	-	-	237
32 Stone, clay, glass	-	2,706	8,216	1,046	380	12,348
33 Primary metals	-	3,139	83,106	158	75	86,478
34 Fab. metals	46	115	2,254	95	109	2,619
35 & 36 Machinery	-	208	1,978	309	115	2,610
37 Trans. eqmt.	23	753	3,440	260	204	4,680
38 Instruments	-	120	260	90	8	478
39 Miscellaneous	-	71	153	-	27	251
Total	841	36,678	240,274	12,116	16,477	306,386

Source:

TABLE 7

Maryland Industrial Fresh Water Intake Projections, 1970

(000 gal. per day)

	Regions					
Industry	Southern Md. I	Western Md. II	Baltimore Metro. III	Washington Metro. IV	Eastern Shore V	Total
20 Food	1,222	3,573	20,363	4,386	11,798	41,342
21 Tobacco	-	-	8	-	-	8
22 Textiles	-	1,290	767	-	79	2,136
23 Apparel	-	54	405	2	27	488
24 Lumber	717	391	1,306	391	1,372	4,177
25 Furniture	-	10	126	13	2	151
26 Paper	-	20,200	62,432	3,671	1,835	88,138
27 Printing	2	41	482	115	32	672
28 Chemicals	508	4,841	89,607	31,942	10,691	137,589
29 Petroleum	1,621	1,621	16,224	4,868	-	24,334
30 Rubber	-	2,487	7,358	413	413	10,671
31 Leather	-	82	156	-	-	238
32 Stone, clay, glass	257	2,712	8,652	2,841	386	14,848
33 Primary metals	-	2,715	90,229	1,358	226	94,528
34 Fab. metals	-	112	2,536	265	150	3,063
35 & 36 Machinery	-	243	2,391	1,019	156	3,809
37 Trans. Eqmt.	74	904	5,043	926	347	7,294
38 Instruments	-	123	394	249	21	787
39 Miscellaneous	-	79	219	5	46	349
Total	4,401	41,478	308,698	52,464	27,581	434,622

Source:

TABLE 8

Maryland Industrial Fresh Water Intake Projections, 1980

(000 gal. per day)

Industry	Regions Southern Md. I	Western Md. II	Baltimore Metro. III	Washington Metro. IV	Eastern Shore V	Total
20 Food	1,559	3,992	38,599	5,117	13,397	62,664
21 Tobacco	-	-	8	-	-	8
22 Textiles	-	1,249	767	-	79	2,095
23 Apparel	-	54	441	5	32	532
24 Lumber	915	391	1,372	457	1,569	4,704
25 Furniture	-	13	142	16	2	173
26 Paper	-	22,035	74,506	4,591	1,835	102,967
27 Printing	2	41	539	164	49	795
28 Chemicals	1,222	9,290	112,894	40,649	15,272	179,327
29 Petroleum	1,783	1,783	21,416	5,353	-	30,335
30 Rubber	-	2,437	8,602	517	621	12,227
31 Leather	-	82	136	-	8	226
32 Stone, clay, glass	257	2,712	9,556	3,358	517	16,400
33 Primary metals	-	2,783	99,459	1,391	232	103,865
34 Fab. metals	-	131	2,895	358	189	3,573
35 & 36 Machinery	10	304	3,405	1,556	254	5,529
37 Trans. eqmt.	115	1,068	6,805	1,290	431	9,709
38 Instruments	21	164	580	435	21	1,221
39 Miscellaneous	5	112	304	5	65	491
Total	5,889	48,691	382,426	65,262	34,573	536,841

Source:

TABLE 9

Maryland Industrial Fresh Water Intake Projections, 2010

(000 gal. per day)

	Regions					
Industry	Southern Md. I	Western Md. II	Baltimore Metro. III	Washington Metro. IV	Eastern Shore V	Total
20 Food	2,744	6,081	26,381	6,276	17,622	59,104
21 Tobacco	-	-	8	-	-	8
22 Textiles	-	1,049	523	-	79	1,651
23 Apparel	-	60	476	19	46	601
24 Lumber	1,175	391	1,372	457	1,830	5,225
25 Furniture	5	19	189	24	5	242
26 Paper	917	33,969	112,931	8,263	3,671	159,751
27 Printing	16	57	726	227	8	1,034
28 Chemicals	1,736	14,854	188,408	57,772	24,311	287,081
29 Petroleum	4,641	4,641	37,123	11,600	2,320	60,325
30 Rubber	104	3,213	11,504	1,139	931	16,891
31 Leather	-	82	109	-	8	199
32 Stone, clay, glass	386	3,098	11,364	4,132	646	19,626
33 Primary metals	-	3,060	112,223	1,531	255	117,069
34 Fab. metals	38	189	3,956	512	304	4,999
35 & 36 Machinery	43	627	7,230	3,613	597	12,110
37 Trans. eqmt.	301	2,227	13,433	2,484	1,291	19,736
38 Instruments	82	331	1,304	931	41	2,689
39 Miscellaneous	32	205	610	19	158	1,024
Total	12,220	74,153	529,870	98,999	54,123	769,365

Source:

sewage systems which, as was pointed out in Chapter III, then discharge the effluent into estuaries. We have assumed that this will continue to be the case and have therefore assumed that all the projected withdrawals in these regions will be consumptive. In Region II, Western Maryland, all discharges are to fresh water bodies. In that Region, consumption results from leakage out of water supply and waste disposal systems, from evaporation of water used for cooling, from incorporation of water in products, and from discharge of effluent to ground water rather than surface water. The importance of these factors varies from industry to industry, but for most industries consumption is usually estimated at five to ten percent of withdrawals. In our projections we have used ten percent. For the Washington, D.C. Region, this report assumes fifty percent of fresh water withdrawals to be consumptive, to allow for the likelihood that some discharges will be to fresh water and some to brackish water.

In estimating consumptive uses of water, allowance has been made for seasonal fluctuation in water use by several industries, especially food processing. The calculations described above yielded medium projections of water consumption by two-digit industry, by State Regions, for 1970, 1980 and 2010. This detailed procedure cannot easily be followed in making high and low projections since, as stated in Chapter II, we have high and low employment projections only for employment as a whole, and not by two-digit manufacturing industry. Therefore, high and low projections of industrial fresh water consumption were calculated as follows: From the medium projections of industrial water consumption described above, water consumption per employee was calculated for employment as a whole for each of the five Regions and each of the years 1970, 1980 and 2010. These projected water consumption per employee figures were then multiplied by our high and low projections of employment in Table 3, Chapter II. This calculation gives high and low projections of industrial fresh-water consumption for manufacturing as a whole, by State Region, for 1970, 1980 and 2010. The implicit assumption in this method of making high and low projections is that the percentage distribution of total employment among two-digit manufacturing industries is the same for the high and low employment projections as for the medium projections.

The resulting high, medium and low projections of industrial fresh-water consumption are shown in Table 10. According to the medium projections, industrial consumption of fresh water will increase by almost 40 percent between 1960 and 1970, by 25 percent between 1970 and 1980, and by 40 percent between 1980 and 2010. The 2010 figure will be almost 250 percent of the 1960 figure. The high and low projections are very close to the medium projection in 1970, and diverge from it beyond that date.

E. Thermal electric generation

Water intake for steam electric generation is used almost entirely for cooling. In many areas, steam electric generation is one of the major uses of fresh water, although the amount of water withdrawn per K.W.H. of electricity produced depends, in large degree, on the extent to which water is recirculated. The Federal Power Commission[5] has collected comprehensive data on water use in steam electric utilities. Water consumption in steam electric generation results almost entirely from the evaporation of cooling water. This subject has been studied in detail by Landsberg, Fischmann and Fisher.[6]

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[5] Water Requirements of Electric Utility Steam-Electric Generating Plants in 1959, Federal Power Commission, mimeographed, May 1961.

[6] Resources in America's Future, H. Landsberg, L. Fischmann and J. Fisher, Johns Hopkins Press, 1963, pp. 820 ff.

TABLE 10

Estimates and Projections of Industrial Fresh Water Consumption, 1960 Actual, Projected 1970, 1980, and 2010

(000 gal. per day)

Region	1960	1970	1980	2010
		High		
I - Southern Md.	841	4,401	6,274	16,339
II - Western Md.	3,668	4,325	5,331	10,000
III - Baltimore Metro.	240,274	322,531	423,926	716,487
IV - Washington Metro.	6,058	27,476	41,884	68,287
V - Eastern Shore	16,477	28,633	38,300	71,181
Maryland	267,318	387,366	515,715	882,294
		Medium		
I - Southern Md.	841	4,401	5,899	12,220
II - Western Md.	3,668	4,149	4,869	7,415
III - Baltimore Metro.	240,274	308,698	382,386	529,870
IV - Washington Metro.	6,058	26,232	37,631	49,500
V - Eastern Shore	16,477	27,581	34,573	54,123
Maryland	267,318	371,061	465,358	653,128
		Low		
I - Southern Md.	841	4,401	5,523	9,520
II - Western Md.	3,668	4,004	4,543	5,589
III - Baltimore Metro.	240,274	297,406	349,682	399,286
IV - Washington Metro.	6,058	25,342	34,084	35,368
V - Eastern Shore	16,477	26,423	31,523	39,502
Maryland	267,318	357,576	425,355	489,265

They use a rule of thumb that evaporation of 1 percent of the water reduces its temperature by 10° F. Therefore, the consumption of water per K.W.H. generated depends on how much heat must be dissipated by cooling. As the efficiency of thermal electric plants improves gradually through time, there is a gradual decrease in the amount of heat to be dissipated per K.W.H. generated. Based on historical and projected heat rates in thermal electric generation, Landsberger, Fischmann and Fisher estimate gallons of water evaporated per K.W.H. generated as follows:

1960 - 0.76
1970 - 0.67
1980 - 0.58
2010 - 0.42

These figures are based on calculations that are correct when water is cooled in cooling towers, but are of doubtful accuracy if water is cooled in streams after discharge from the generating plant. Instream cooling takes place by convection as well as by evaporation, and the mix of the two presumably depends on a number of stream characteristics. Nevertheless, the figures quoted above have been used in the following calculations.

In Maryland, two factors greatly complicate the problem of estimating and projecting fresh water consumption in thermal electric generation: First, most of Maryland's thermal electric capacity is located on tidewater, and, in consequence, uses brackish water for cooling. In 1959, 81 percent of the water used for thermal electric generation in Maryland was brackish. As fresh water becomes relatively more expensive, as the output of electricity grows, and as the transmission of electricity over long distances becomes cheaper and more efficient, the tendency to locate steam electric capacity on tidewater will presumably grow. Second, much of the electricity consumed in Western Maryland is produced outside the State. As long-distance transmission becomes more economical, discrepancies between the location of production and consumption of electricity will presumably become more common.

In view of the above considerations, it is anticipated that future increases in fresh-water consumption for thermal electric generation in Maryland will be modest. Small increases are projected, however, in steam electric production with fresh water in those regions of the State that do not have easy access to brackish water supplies. These projected increases are mainly intended to allow for the expansion of steam electric plants now in existence, and are much smaller than reasonable projections of the growth of total electricity consumption in Maryland. Multiplying the figures for projected production using fresh water by the figures quoted above from Landsberg, Fischmann and Fisher for water evaporation per K.W.H. produced, yielded our medium projections of fresh water consumption for steam electric generation. High and low projections were obtained by computing water consumption per capita from the medium projections and multiplying by our high and low population projections in Chapter II. The resulting projections are presented in Table 11.

TABLE 11

Projections of Fresh Water Consumption in Steam Electric Generation, Actual 1960, Projected 1970, 1980, and 2010

(000 gal. per day)

Region	1960	1970	1980	2010
High				
I - Southern Md.	-	-	-	-
II - Western Md.	1,595	1,734	1,945	3,806
III - Baltimore Metro.	-	-	-	-
IV - Washington Metro.	4,737	5,776	6,203	9,388
V - Eastern Shore	-	-	-	-
Maryland	6,332	7,510	8,148	13,194
Medium				
I - Southern Md.	-	-	-	-
II - Western Md.	1,595	1,652	1,748	2,301
III - Baltimore Metro.	-	-	-	-
IV - Washington Metro.	4,737	5,507	5,562	6,904
V - Eastern Shore	-	-	-	-
Maryland	6,332	7,159	7,310	9,205
Low				
I - Southern Md.	-	-	-	-
II - Western Md.	1,595	1,594	1,607	2,128
III - Baltimore Metro.	-	-	-	-
IV - Washington Metro.	4,737	5,324	5,112	5,224
V - Eastern Shore	-	-	-	-
Maryland	6,332	6,918	6,719	7,352

CHAPTER V

AGRICULTURAL USES OF WATER

A. Introduction

Agriculture, which accounts for nearly half of all withdrawals of water, and an even higher proportion of all consumptive uses throughout the United States, is quantitatively a much less important water-user in Maryland. However, its relatively modest demand upon the State's water supply (a factor observable along all of the humid Eastern Seaboard) has been increasingly raised by more highly productive crops and agricultural techniques. These have taken progressively larger quantities of water since 1950, and this expanding demand may be expected to continue. Because this expansion is most readily apparent along the Delmarva Peninsula where the climate, soils, and topography have encouraged agricultural advancements, much of this chapter's discussion will deal with Region V, the Eastern Shore.

This chapter, then, is divided into two parts: The first describes methods and assumptions used in arriving at projections for land use changes. The second analyzes the characteristics, costs, and returns of irrigation as it is now practiced in Maryland, with the focus on the Eastern Shore; further, it calculates water requirements, and demand and supply problems relevant to future expansion.

B. Estimates of cropland

In order to estimate the agricultural demand for water in Maryland, it is necessary to make estimates of future cropland. These estimates are in acres of cropland harvested, as defined in the Census of Agriculture, and do not include pastured land and woodland. The irrigation of pasture does not appear to be profitable, nor is it likely to become profitable in this State, since additional land for pasture is abundant and feed-crops can also be grown, so that herds may be enlarged without increasing pasture yields through irrigation.[1]

There are three distinct problems, requiring three sets of considerations in estimating future cropland.

1. In the metropolitan counties (Regions III and IV), in which population increases will be large, cropland is being converted to intensive uses such as suburban housing, highways, parkland, airports, etc. This is occurring to some extent in all counties, but is the dominant process in the metropolitan counties, accounting for rapidly declining acreage of cropland harvested.

2. In Western Maryland (Region II), in addition to land taken for intensive uses, much cropland is being shifted to pasture and woods, as the farm economy turns increasingly to dairying. The adjustment is generally seen as desirable from the standpoint of erosion control, high-yield farming, and regional income, since much of the topography is too rugged for efficient modern crop farming. In spite of very small changes in population, therefore, acreage of cropland has declined.

3. On the Eastern Shore (Region V) and in Southern Maryland counties (Region I), population changes have been small, and some cropland has been converted to intensive uses; but offsetting this decline, drainage projects have contributed to the recovery or reclamation of land and its conversion

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[1] Evaluating the Profitability of Irrigation of Northeastern Dairy Farms, general discussion of irrigation and dairy economics, New Hampshire Agricultural Experiment Station, Bulletin 469, 1960.

from woods or pasture to cropland; cropland harvested, consequently, has increased.

Estimates of cropland taken for intensive uses have been made for the counties by two distinct methods, described and justified independently, and the results have been compared and found similar. These estimates have then been adjusted for changing land use in Western Maryland and on the Eastern Shore.

1. Method I

The principle employed here was to observe the relation between population density and percentage of cropland in the counties of Maryland in 1950 and 1960, and to extrapolate rates of disappearance of cropland according to projected changes in density of population for 1980 and 2010.

Certain combinations of population density (persons per acre) and percentage of cropland (acres of cropland per acre of total land area by county) characterize the farming regions of the State in a consistent manner, as shown for 1950 in Figure 1, which also shows the combinations for 1960. The vectors measure the changes from 1950 to 1960. The counties of rapid suburban growth, which experienced the highest increases of population density in that decade, show a consistent pattern of vectors of the same slope. In those counties, the percentage of cropland declined at a consistent rate proportional to population growth. Therefore, these counties were selected for a regression, to establish the formula by which the projections were made: Montgomery, Baltimore, Prince George's, Anne Arundel, Harford, Calvert, Charles, and Cecil. The results are as follows:

$$Y = 7.78 X + .82$$

X is he increase in population density from 1950 to 1960 (density 1960 minus

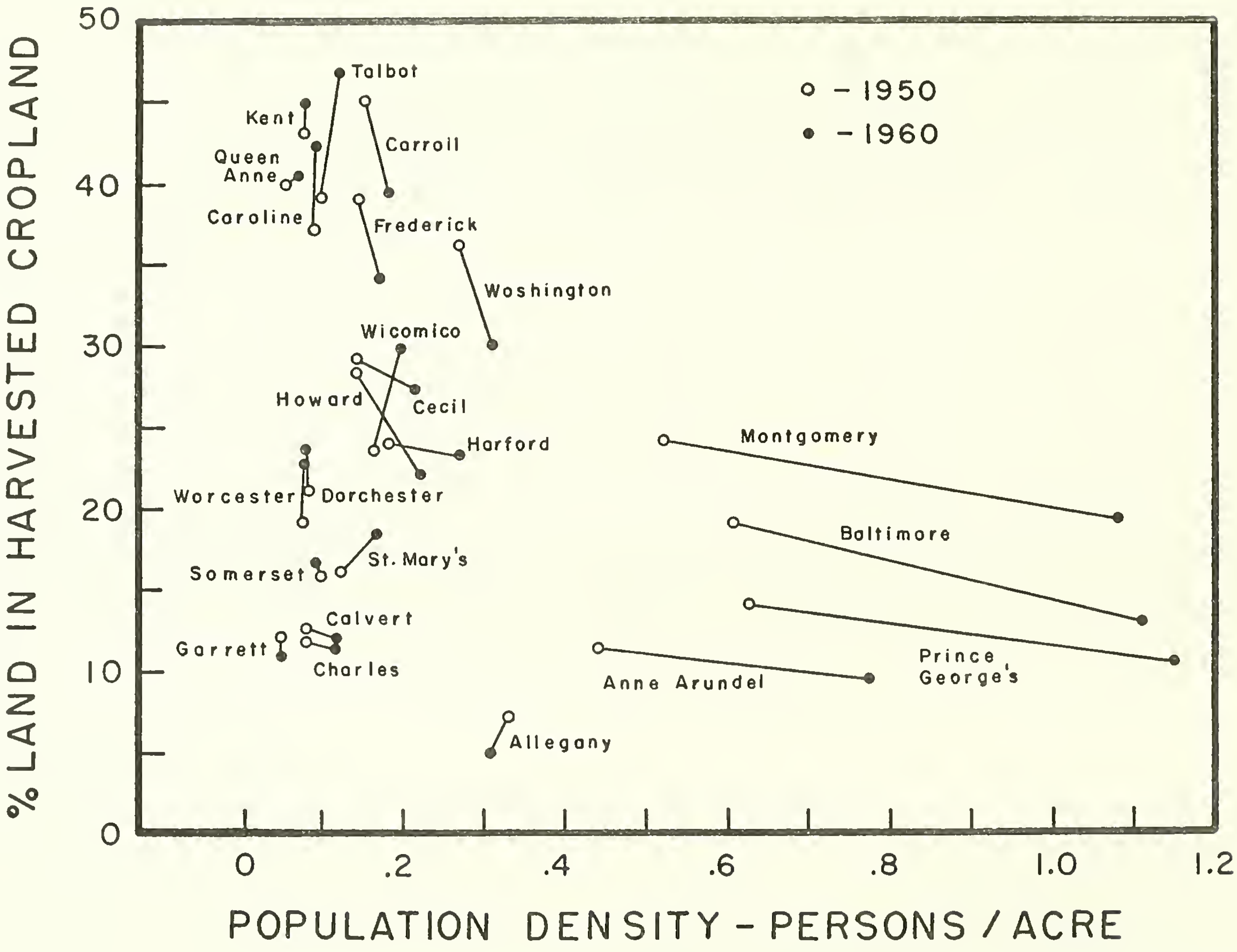

Figure 2

Change 1950-1960 in Percent Land Area in Harvested Cropland and Population Density, Maryland Counties density 1950, no change in total land area of counties), and Y is cropland harvested in 1950 minus cropland harvested in 1960, expressed as percent of total land area of county.

The formula implies the following: Regardless of change in density, .82 percent of the land area will be converted to intensive uses in a decade; in addition, when the average density of population of the county is increased by one more person per acre, an acreage equivalent to 7.78 percent of the land area of the county will have been converted from harvested cropland to intensive uses.

The formula is used to project percentages of cropland lost up until 1980 and 2010 for all counties, using as X the population densities presented in the Chapter II projections for 1980 and 2010. The percentages are shown in columns 15 and 16 of Table 1; the acres of cropland remaining are shown in columns 19 and 20, with adjusted forecasts in columns 21 and 22 (adjustments described below).

2. Method II

Land-use studies often assume a per capita factor, an amount of space required per person for metropolitan purposes. These have been derived by looking at population densities of metropolitan areas, and at acquisitions of land for urban special uses over the last ten, twenty or thirty years.[2] These range from .17 to .27 acre per person. The .27 figure is used here for several reasons: (a) The population projections themselves are based

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[2] See Donald Bogue in various Scripps Foundation publications, or Land for the Future, Marion Clawson, R.B. Held, and C.H. Stoddard, Johns Hopkins Press, 1960.

TABLE 1

Land Use Estimates, Method I (Preferred)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Maryland	6,323	1,531	1,454	24.2	23	-1.2	.371	.491	4,623	7,453
Calvert County	140	18	17	12.8	12.1	-0.7	.086	.114	22	37
Charles	293	36	33	12.3	11.3	-1.0	.078	.113	53	105
St. Mary's	235	38	43	16.2	18.3	+2.1	.123	.166	63	120
Region I - Southern Md.	668	92	93	14	14	0	.097	.13	138	262
Allegany	273	20	14	7.3	5.1	-2.2	.33	.308	84	127
Frederick	425	164	145	38.7	34.2	-4.5	.146	.17	94	160
Garrett	424	50	46	11.8	10.8	-1.0	.05	.047	18	34
Washington	296	107	89	36.2	30.1	-6.1	.267	.308	114	176
Region II - Western Md.	1,418	341	294	24	21	-3.0	.178	.2	310	497
Baltimore County	441	85	56	19.3	12.7	-6.6	.611	1.11	950	1,700
Anne Arundel	267	31	25	11.6	9.4	-2.2	.438	.775	403	790
Carroll	292	132	115	45.3	39.5	-5.8	.154	.182	77	136
Harford	287	70	67	24.4	23.4	-1.0	.181	.268	144	288
Howard	161	45	36	28	22.3	-5.7	.143	.224	68	153
Region III - Baltimore Met. (excl. Baltimore City)	1,448	363	299	25	21	-4.0	.35	.59	1,642	3,067
Montgomery	316	77	61	24.4	19.3	-5.1	.52	1.08	646	1,096
Prince George's	310	44	32	14.2	10.3	-3.9	.63	1.15	674	1,169
Region IV - Washington Met.	626	121	93	19	15	-4.0	.57	1.11	1,320	2,265
Cecil County	225	66	60	29.4	26.7	-2.7	.148	.215	84	135
Caroline	205	76	87	37.1	42.5	+5.4	.088	.093	18	29
Dorchester	371	77	87	20.8	23.5	+2.7	.076	.081	32	43
Kent	182	78	82	43	45	+2.0	.077	.082	18	29
Queen Anne's	239	96	97	40.3	40.6	+0.3	.063	.071	18	29
Somerset	212	34	35	16.1	16.5	+0.4	.1	.094	22	30
Talbot	179	70	84	39.1	47	+7.9	.106	.123	28	35
Wicomico	243	57	72	23.5	29.7	+6.2	.165	.202	65	99
Worcester	309	61	70	19.3	22.7	+3.4	.074	.078	28	35
Region V - Eastern Shore										
(excl. Cecil)	1,940	549	614	28	32	+4.0	.091	.109	229	329
(incl. Cecil)	2,165	615	671	28	31	+3.0	.097	.113	313	464

Source: U. S. Census of Agriculture

TABLE 1

Land Use Estimates, Method I (Preferred)
(continued)

(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)
.731	1.179	.240	.447	2.688	4.298	20.312	16.014	1,284	1,013	1,304	1,078	3,101
.157	.264	.043	.107	1.155	1.652	10.945	9.293	15	13	-	-	16
.181	.358	.068	.177	1.349	2.197	9.951	7.754	29	23	-	-	33
.268	.511	.102	.243	1.614	2.711	16.686	13.975	39	33	-	-	39
.207	.392	.077	.185	1.419	2.259	12.581	10.322	84	69	-	-	88
.308	.465	.000	.157	.820	2.041	4.280	2.239	12	6	11	5	84
.221	.376	.051	.155	1.217	2.026	32.983	30.957	140	132	136	127	72
.042	.080	-.005	.038	.781	1.116	10.019	8.903	42	38	38	34	20
.385	.595	.077	.210	1.419	2.453	28.681	26.228	85	78	80	73	91
.219	.350	.019	.131	.968	1.839	20.032	18.193	284	258	270	243	267
2.154	3.855	1.044	1.701	8.942	14.054	3.758	-10.296	17	0	-	-	492
1.509	2.959	.734	1.450	6.531	12.101	2.869	-9.232	8	0	-	-	207
.264	.466	.082	.202	1.458	2.392	38.042	35.650	111	104	-	-	53
.502	1.003	.234	.501	2.641	4.718	20.759	16.041	60	46	-	-	77
.422	.950	.198	.528	2.360	4.928	19.940	15.012	32	24	-	-	36
1.134	2.118	.544	.984	5.052	8.476	15.948	7.472	231	108	-	-	865
2.044	3.468	.964	1.424	8.320	11.899	10.980	-.919	35	0	-	-	341
2.174	3.771	1.024	1.597	8.787	13.245	1.513	-11.732	5	0	-	-	357
2.109	3.618	.999	1.509	8.592	12.560	6.408	-6.152	40	0	-	-	698
.373	.600	.158	.227	2.049	2.586	24.651	22.065	55	50	-	-	48
.088	.141	-.005	.053	.782	1.232	41.718	40.487	86	83	88	91	19
.086	.116	.005	.030	.859	1.053	22.641	21.588	84	80	88	90	30
.099	.159	.017	.060	.952	1.287	44.048	42.761	80	78	83	84	15
.075	.121	.004	.046	.851	1.178	39.749	38.571	95	92	98	100	17
.104	.142	.010	.038	.898	1.116	15.602	14.486	33	31	36	40	20
.156	.196	.033	.040	1.077	1.131	45.923	44.792	82	80	86	90	22
.267	.407	.065	.140	1.326	1.902	28.374	26.472	69	64	75	80	49
.091	.113	.013	.022	.921	.991	21.779	20.788	67	64	72	75	24
.118	.170	.009	.052	.890	1.225	31.110	29.885	604	580	626	651	196
.145	.214	.032	.069	1.069	1.357	29.931	28.574	648	619	682	700	244

TABLE 1

Land Use Estimates, Method I (Preferred)

(1) Land area of counties in thousands of acres, 1954

(2) Cropland harvested, thousands of acres, 1949

(3) Cropland harvested, thousands of acres, 1959

(4) Cropland as percent of land area, 1949

(5) Cropland as percent of land area, 1959

(6) Change in percent of cropland, 1949-1959

(7) Density: population per acre, 1950

(8) Density: population per acre, 1960

(9) Population projected for 1980, in thousands

(10) Population projected for 2010, in thousands

(11) Density projected, 1980

(12) Density projected, 2010

(13) Difference of population density, 1960-1980

(14) Difference of population density, 1980-2010

(15) Estimated reduction in cropland as percent of land area, 1960-1980

(16) Estimated reduction in cropland as percent of land area, 1980-2010

(17) Remaining cropland as percent of land area, 1980

(18) Remaining cropland as percent of land area, 2010

(19) Cropland forecast (1000 A.), 1980

(20) Cropland forecast (1000 A.), 2010

(21) Cropland forecast, 1980, adjusted

(22) Cropland forecast, 2010, adjusted

(23) Population, 1960, in thousands

on rather low densities of population and rapid outward growth of the urban areas, so that the larger acreage per capita appears consistent with the assumptions underlying our population projections. (b) The availability and easy access of land in Eastern, Western and Southern Maryland makes it reasonable to assume low densities for future metropolitan development for Baltimore and Washington. (c) The larger acreage per capita is consistent with policies for reservation of parklands, recreational areas, and watershed protection which have been recommended by planning agencies in the State.

The projected increases in population for each county were multiplied by 0.27 acres to yield projected acreage converted to urban uses. It is then necessary to calculate the proportion of the converted acreage which will be taken from cropland, excluding woodland, pasture, etc. This is done by choosing a factor for each county equal to twice the percentage of its total land area which is now in harvested cropland (1959). The percent of cropland is arbitrarily multiplied by two in order to allow for the fact that cropland is generally more level, better drained, cleared, or more accessible, and therefore taken at a greater rate than other kinds of lands for new housing development, industrial uses, etc. A factor as great as three might be reasonable.

This method is used as a check on the first. The results projected to 1980 and 2010 are shown in columns 8 and 9 of Table 2, and when they are compared with the results of Method I (Table 1, columns 19 and 20), it is found that the chief discrepancies refer to Anne Arundel, Baltimore, Prince George's and Montgomery Counties. That is, the per capita factor method leaves considerable amounts of land in cropland in these suburban counties.

TABLE 2

Land Use Estimates, Method II

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Maryland	1,522	2,830	410.9	764.1	46	189.03	351.49	1,265	913
Calvert County	7	14	1.9	3.8	24	.45	.91	17	16
Charles	22	49	5.9	13.2	22	1.31	2.91	32	29
St. Mary's	26	54	7.0	14.6	36	2.53	5.25	41	35
Region I - Southern Md.	55	118	14.8	31.9	28	4.16	8.92	89	80
Allegany	-1	29	-.3	7.8	10	-.03	.78	14	13
Frederick	20	50	5.4	13.5	68	3.67	9.18	160	151
Garrett	-2	12	-.5	3.2	22	-.12	.71	50	49
Washington	21	44	5.7	11.9	60	3.40	7.13	104	96
Region II - Western Md.	38	135	10.3	36.4	42	4.31	15.31	290	274
Baltimore County	423	576	114.2	155.5	25*	28.55	38.88	27	-11
Anne Arundel	181	305	48.9	82.4	18*	8.80	14.82	16	1
Carroll	21	45	5.7	12.1	80	4.54	9.72	110	101
Harford	62	114	14.0	33.5	46	6.46	15.40	61	45
Howard	29	69	7.8	18.6	44	3.44	8.20	33	24
Region III-Baltimore (excl.)	716	1,109	193.3	299.4	42	81.19	125.76	218	92
" (incl.)	739	1,437							
Montgomery	306	471	82.6	127.2	38*	31.39	48.32	30	-19
Prince George's	318	517	85.9	139.6	20*	17.17	27.92	15	-13
Region IV - Washington Metro.	624	988	168.5	266.8	30*	50.54	80.03	42	-37
Cecil County	35	59	9.4	15.9	54	5.10	8.60	55	46
Caroline	-1	12	-.3	3.2	85	-.23	2.75	87	84
Dorchester	2	13	.5	3.5	47	.25	1.65	87	85
Kent	3	12	.8	3.2	90	.73	2.92	81	78
Queen Anne's	1	12	.3	3.2	81	.22	2.62	97	94
Somerset	-2	4	-.5	1.1	33	-.18	.36	35	35
Talbot	6	9	1.6	2.4	94	1.52	2.28	82	80
Wicomico	16	39	4.3	10.5	60	2.59	6.32	69	63
Worcester	4	9	1.1	2.4	45	.49	1.09	70	68
Region IV - Eastern Shore									
(excl. Cecil)	30	109	8.1	29.4	64	5.18	18.84	609	590
(incl. Cecil)	66	167	17.8	45.1	62	11.05	27.96	660	632

Source: U.S. Census of Agriculture.

TABLE 2

Land Use Estimates, Method II, for Comparisons Only

(1) Difference between population 1960 and projected population 1980, in thousands

(2) Difference between projected populations 1980 and 2010, in thousands

(3) Land converted to special uses by 1980, thousands of acres

(4) Land converted to special uses by 2010, thousands of acres

(5) Percent required from cropland (2x cropland as percent of land area in 1960)

(6) Loss of cropland 1960-1980, thousands of acres

(7) Loss of cropland 1980-2010, thousands of acres

(8) Cropland remaining in 1980, thousands of acres

(9) Cropland remaining in 2010, thousands of acres

Note: Calculated to three decimal places, numbers in tables rounded.

This is not justified, since, if it were true, population could be expected to increase further in those counties before spilling over into the surrounding suburban counties. This result suggests that a higher factor than two should be used to multiply percent of cropland. The results of Method I have been adopted as more consistent and more reliable.

The method employed by the Kerr Committee Report (Kerr Committee, Print No. 12, p. 58) was to use a factor of 0.5 acres per person for all regions of the U.S., in spite of recognized variation in regions and kinds of areas, and to distribute this loss in direct proportion to 1954 percentages of land uses. That procedure is simpler but less realistic in its assumptions. The results applied to Maryland's counties would resemble those of Method II.

3. Adjustments

It is entirely possible that the relations observed between population densities and land use changes in the last ten years will not hold for the future. If they do not, population estimates will probably fall short of actual population. It is difficult to imagine the taking of much more land for highways after about 1980, but it is possible that more land will then be required for small airports, protected open spaces, and recreational land.

No special calculations have been made for Federal land, although the quantities already taken for military uses in Maryland have been very large. They will not diminish, but (a) much of that land is shore and wetland, (b) the unused land has not been greatly disturbed in its drainage and vegetation, and (c) as with civilian-owned land, its conversion to intensive uses is a function of the population of the base.

In Region II, adjustments were made to show decreases in cropland harvested in Garrett and Allegany Counties, despite the stable populations

TABLE 3

Area Drained, Southern and Eastern Shore Counties

	(1)	(2)	(3)
Calvert	0		
Charles	0		
St. Mary's	0		
Southern Maryland	0		
Cecil	0		
Caroline	56	27	2.4
Dorchester	52	14	0
Kent	0	0	0
Queen Anne's	67	28	2
Somerset	71	33	1.2
Talbot	0	0	0
Wicomico	55	23	2.3
Worcester	48	16	1.1
Eastern Shore (excl.)	349	18	9
Eastern Shore (incl.)	349	16	9

(1) Net area drained and used for agriculture, in projects over 500 acres, 1959 Census of Agriculture, thousands of acres.

(2) Same, as percent of total land area

(3) Net area newly drained, in large projects, 1950-1960

projected, and cropland decreases were accentuated slightly for 1960 to 1980 for Frederick and Washington Counties, to allow for the continuing trend of adjustment of cropland to topography, and rural emigration. No changes were made for 1980-2010, on the grounds that the adjustment would be complete by 1980.

Cecil County, which has some of the characteristics of an Eastern Shore county, a metropolitan county, and a Piedmont county, was left as projected by Method I; this conforms to the trend in land use in that county from 1950 to 1960. Tabulations include two sets of figures, one for the Eastern Shore including Cecil County, so that Region V corresponds to the region described in other parts of the report, and the other excluding Cecil County, in order to provide a more homogeneous grouping for discussion purposes.

On the Eastern Shore, predictions of cropland acreage are more important because irrigation is practiced on a larger scale; but here, too, predictions are more difficult. The estimates are adjusted (Table 1, columns 21 and 22) to show a net increase in cropland for all of these counties, although the increase is very small for those in which population density is expected to increase.

All of the Eastern Shore counties, as well as St. Mary's in Southern Maryland, showed large increases in percentage of cropland harvested between 1949 and 1959 (Table 1, column 6). Some of this was made possible by drainage projects. Table 3, column 3, gives some indication of newly drained acreage, 1950-1960, but it includes only large-scale drainage projects, of more than 500 acres each.

The soil conservation watershed work plans for Timmonstown Branch (Worcester County), Gilbert Run (Charles and St. Mary's), and Aydelotte watershed (Wicomico County) give some idea of current drainage activities. Federal assistance in planning and financing such small watershed land management projects is available and is likely to be extended to other watersheds. Areas which lend themselves to drainage and irrigation treatment are located almost exclusively in Eastern and Southern Maryland. Average increases in yields of corn and soybeans of 150 to 200 percent of present yields in those watersheds are anticipated by Federal agencies, but without shifts in cropland. The plans favor sylviculture, mechanization of farming, and diversification of crops (especially in Southern Maryland), but in the past, drainage projects on the Eastern Shore have in fact been associated with increases in cropland harvested and increases in the vegetable crops as well as less intensive feed crops, and not sylviculture.

The counties of Southern Maryland (Calvert, Charles, and St. Mary's) were left as calculated by Method I, since the projected population changes are moderate. Although it is likely that drainage work will continue, changes in crops and a probable increase in dairying may offset the adding of cropland acreage. The rapidity of these changes and the speed with which new cropland is brought into cultivation in that area may well depend on the speed with which urbanization in these counties creates new markets and social change. The two changes - new cropland and cropland conversion to intensive uses - will therefore tend to offset each other, leaving net cropland relatively stable.

C. Irrigation as practiced in Maryland

1. Factors peculiar to Maryland irrigation practices

Maryland irrigation practice differs in many ways from the use of water in arid parts of the nation. The public, including urban Marylanders, are accustomed to thinking of irrigation in terms of dryland reclamation, but the considerations for public policy are not the same.

a) 100 percent consumption: In sprinkler irrigation, as it is practiced here, practically 100 percent of the water taken into the system is consumed or depleted - evaporated from the soil or transpired by the plants. In Western ditch-irrigation, as much as 25 to 40 percent is returned to streams.

b) No pollution: Because very little of the water is returned, Maryland irrigation practice normally does not pollute the streams with salts, sediment, fertilizer, etc. (discussed further in section C). Irrigation is a severely polluting use in the West.

c) Less waste: There is less waste of water in Maryland-style irrigation. About 25 percent is lost in evaporation, but this is a smaller percentage than in the dry climates, and smaller than with ditch-methods common in the West. Because Maryland has large summer rainfalls, the farmer must take care not to apply too much water in irrigation. In the West, laws of prior use lead many farmers to waste water in order to protect their right to a greater supply at some future date. Maryland riparian law does not recognize such priority, and there is no legal incentive to waste water.

d) Farm storage: As a rule, the Maryland farmer pays all the costs of pumping and storage of the water, as well as sprinkler operation, etc. In the West, water is delivered to the farm at a cost which is often borne in part by taxes and charged to other uses such as flood control, recreation, or power. In dry regions where rain is sharply seasonal and may vary from year to year, the storage system must be built to handle a full year's supply or more. In Maryland, farmers generally store their own water or run the risks of shortage; there are few cases where they benefit from any major community storage system. They commonly follow a rule of storing one acre-foot or less for each acre they plan to irrigate, because they can, in normal years, expect to recharge or refill their storage ponds several times during the summer; in abnormal years, they run the risks of diminished flows or dry wells.

e) Less water per acre: Compared to dry-land irrigation, Maryland irrigators use very little water on a single acre. The amount varies more from year to year. As shown by the Irrigation Survey of 1959, the average application of water in the State was 4.215 acre-inches per acre. It is probably 6 or 7 inches for nursery crops, and about 3 inches for lima beans, field-corn, or other crops which are irrigated incidentally. Experiments at Beltsville and Salisbury have shown that in a particular location in some years irrigators may apply no water at all or as much as 10 or 12 inches, depending upon the timing of rains. However, dry-land irrigation in Kansas or Wyoming employs as much as 3 or 4 acre-feet (36 to 48 acre-inches) of water per acre each year.

f) High-return crops: The crops raised under irrigation in Maryland are generally the high-priced crops: fresh vegetables, tomatoes, greens, strawberries, etc. While this is true also for parts of California and Arizona, a great deal of dry-land irrigation in the West is employed to raise wheat, alfalfa, sugar-beets, and other crops which have relatively low returns per acre, which employ fewer people in growing, handling and marketing, and for which the market is oversupplied and the price supported.

g) High-investment crops: The crops raised under irrigation in Maryland are high-cost crops. If irrigation is not employed, the planted crop is likely to be very poor about one year in three, and losses are considerable, because these vegetable and fruit crops require care and investment in labor before harvest. In the arid lands without irrigation, no crop would be planted and no settlement would occur; this is not the same kind of loss of income as that which minor drought causes in Maryland.

h) High value of water: Because so little water is applied per acre, and because the farmer is growing crops here which risk a large investment if they fail, but produce a high return when they are irrigated, irrigation produces a high gross return per acre of land irrigated, or per acre-inch of water used. The gross return per acre irrigated is of the same order as in Western irrigation, but the return per acre-inch of water used is much higher in Maryland.

The attempt was made to estimate the value obtained from irrigation and from the average quantity of water applied in irrigation, for several reasons: it verifies the suspicion that irrigation produces greater returns on the Shore than in arid regions; it permits rough comparisons of the economic value of water in alternative uses such as flows available for producing power, diluting wastes, etc.; and it suggests the further incentives to the expansion of irrigation and the magnitude of the benefits.

2. Costs of irrigation

The costs of sprinkler irrigation appear to depend mainly on the number of acres irrigated by the system, the size of farm operations, and the source of water. Operating costs are higher in dry years: the cost of pumping varies with volume pumped; the largest factor in operating costs is the labor to move the irrigation equipment. Shortly after World War II, light-weight pipe came into use, labor costs were decreased, and this reduction in operating costs helps account for the rapid development of sprinkler irrigation in the eastern United States.

A survey in Delaware established costs of irrigation ranging from $71 per acre for farms irrigating less than 25 acres, to $16 per acre for farms irrigating over 150 acres, with an average total cost of irrigation for the 206 farms of about $20 per acre, and an average number of acres irrigated 50, 56, and 53 for the respective years 1956, 1957, and 1958.[3] The type of irrigation, average number of acres irrigated, crops, soils and climate correspond closely to the Eastern Shore counties of Maryland, including Cecil County (see Tables 4 and 5). The average total cost of irrigation on the Eastern Shore is therefore estimated at about $20 per acre for the purposes of this analysis.

In the fruit-growing and nursery-crop areas in the rest of Maryland, the average acreage irrigated per system is much less, about 26 acres, and the average total cost perhaps $50 or $60 per acre, but large individual systems probably meet the low costs of Eastern Shore practice.

Water sources are stream supply, recharge ponds or dug wells (less than 15 feet), sky ponds, drilled wells (usually shallow, 15 or 30 feet), and, rarely, deep wells. Specially designed farm ponds are used for storage, essential where stream supply is the source, as the farmer legally cannot diminish any other downstream user's low flow. Storage often is desirable with well supply because it permits use of a smaller capacity pump, a smaller diameter well, and in some cases a shallower well.

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3. Irrigation in Delaware, Smith, McDaniel, and Scarborough, University of Delaware Agriculture Experimental Station, Technical Bulletin No. 335, July 1960.

TABLE 4

Irrigation by Agricultural Regions

	(1)	(2)	(3)	(4)	(5)
Central & Western Maryland	3,584	33	5.0	19,555	76
Southern Maryland	932	14	4.3	8,305	19
Eastern Shore	8,195	57	3.85	53,046	57
State	12,711	40	4.215	80,906	50

(1) Acres irrigated 1959

(2) Mean number of acres per irrigator 1959

(3) Mean application in acre-inches per acre 1959

(4) Irrigated acreage forecast 1975

(5) Mean number of acres per irrigator 1975

(All data from Survey of Irrigation in Maryland for 1959 Crop Year prepared for the Maryland Water Study Commission, February 1960)

TABLE 5

Irrigation Data and Estimates by Counties and Water Regions

	(1)	(2)	(3)	(4)
Maryland	88,711	12,711	320	40
Calvert	254	30	3	10
Charles	103	92	9	10
St. Mary's	103	58	5	11
Region I - Southern Md.	460	180	17	10
Allegany	255	133	5	27
Frederick	3,343	323	8	40
Garrett	550	236	1	(236)
Washington	714	1,626	17	96
Region II - Western Md.	4,862	2,318	31	75
Baltimore County	7,747	732	52	14
Anne Arundel	1,437	537	27	20
Carroll	6,388	117	4	29
Harford	4,737	24	2	12
Howard	1,222	191	6	32
Region III-Baltimore (excl.)	21,531	1,601	91	18
Montgomery	2,033	202	15	13
Prince George's	668	215	21	10
Region IV - Washington Metro.	2,701	417	36	12
Cecil	2,096	445	8	56
Caroline	9,097	1,324	21	63
Dorchester	10,815	1,795	27	67
Kent	5,732	639	10	64
Queen Anne's	3,572	803	8	100
Somerset	5,137	509	8	64
Talbot	3,585	142	5	28
Wicomico	10,441	1,909	47	41
Worcester	5,974	629	11	57
Region V - Eastern Shore (excl.)	54,323	7,750	137	57
" " (incl.)	56,419	8,195	145	57

(1) Acreage truck 1960
(2) Acreage irrigated 1959
(3) 1959 number of irrigators
(4) Mean number acres/irrigator

Source: Survey of Irrigation in Maryland for 1959 Crop Year prepared for the Maryland Water Study Commission, February 1960.

The incentives to irrigation in Eastern Shore truck farming are high (see next section), and irrigation costs are the brakes on the trend to install irrigation systems. The cheapest supplies are developed first, so that costs of development of supply may rise, although increases in size of system and farm unit may offset this by decreasing operating costs. Some improvements in well-drilling and in pond construction can be expected to reduce costs of developing deep-well supplies. As it becomes necessary to resort to deep aquifers, the costs rise and the trend to irrigate may either (a) cease, with irrigation of truck crops alone, or (b) be temporarily slowed, until returns exceed the higher costs of irrigation from deep wells.

Some deep wells are already in operation, others are planned, and this method of developing an irrigation supply may henceforth expand fairly rapidly on the Eastern Shore. Some examples are cited here to show the difference in types of installation and associated costs.

In the Maryland Irrigation Survey of 1957, A.V. Krewatch gives the following examples: (a) in Queen Anne's County, a 10-inch well, 300 feet deep with water lift of 110 feet, a 6-inch pump of capacity 500 g.p.m., the 1955 cost was: well $3,000, pump $2,900, pond in addition; (b) on Kent Island, a 10-inch well, 275 to 350 feet deep, 500 g.p.m., the cost was: well $4,000, pump $3,500, engine $1,500; (c) in Anne Arundel County, a 6-inch well, 160 feet deep, 50 g.p.m., the cost was: well $1,100, pump $800, electric motor $200, pond $900. (Notice the smaller rate of pumping and investment in well and pumping system, compensated by investment in pond.) (d) Pocomoke, 12-inch well, 65 feet deep, 550 g.p.m., the cost was: well and pump $5,000, engine $500.

A very large well is under construction now in Queen Anne's County of one million gallons per day capacity, at a cost of approximately $5,000 for well and $5,000 for pump and machinery. This one will irrigate 20 acres or more with no storage capacity at the surface.

The dug ponds or seepage ponds, limited in location to shallow water tables, often cost $700 or $800, plus $300 pump, and supply water equivalent to a drilled deep well which might cost ten times as much. That investments of this size for deep wells are made indicates the expected high gross returns to irrigation practice.

3. Returns to irrigation

Estimated returns to irrigation were devised by the Agricultural Experiment Station at the University of Maryland, which provided results of experimental plots of several years' duration, and yields of vegetables with and without irrigation in Eastern Shore soil types at Salisbury and in New Jersey. The yields were averaged over the number of years the experiment had been running, none less than three years. The yield without irrigation was subtracted from the yield under irrigation. The average difference in yield was multiplied by an average price (per bushel or per ton): the resulting figure is called the mean gross return to irrigation, column 2 in Table 6. A mean cost of irrigation of $20 per acre is subtracted to obtain a mean net return to irrigation (column 3). If this is divided by the average number of acre-inches of water applied per acre (column 4), the quotient is a mean net return per acre-inch of water applied (column 6). In column 7 this is converted to a return per thousand gallons, so that it may be compared with other water-prices.

There are a great many drawbacks to this method. It assumes that the experiments covered a long enough time to allow for the normal variability

TABLE 6

Eastern Shore Irrigation Returns by Crops, Experimental Data

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Cucumbers	$483	$398	$378	3.5	4	$108	$3.98
Cabbage	568	247	227	4.6	6	49	1.81
Tomatoes	346	185	165	4.8	6	29	1.07
Snapbeans	210	154	134	2.3	9	58	2.14
Potatoes	367	105	85	3.3	3	26	.96
Carrots	362	76	56	7.8	3	7	.26
Sweet corn	102	23	3	5.4	6	1	.04
Beets		31[a]	11[a]	2.0	4	6	.22

[a] Return on each crop; double for annual return; double water requirement.

(1) Mean annual return per acre without irrigation

(2) Mean gross return to irrigation (return per acre in addition to (1))

(3) Mean net return to irrigation per acre ($20 subtracted as costs)

(4) Mean number of acre-inches of water applied per acre

(5) Number of years of record

(6) Mean net return per acre-inch of water applied (2 divided by 3)

(7) Mean net return per thousand gallons ((4) divided by 27)

Source: Physical data - Unpublished materials, University of Maryland, School of Agriculture.

of rainfall; it assumes that total costs per acre of irrigation do not vary significantly for different crops (although in fact operating costs do vary with amounts of water applied); it assumes that farmers apply water with the same level of efficiency and control as the experiment station. No allowance is made for quality of the crop or time of harvest which may affect price received. However, where we do not have well-designed farm accounts over a long period of record, such assumptions must be made.

Table 6, columns 1 and 2, show that the crops which have a high gross return per acre without irrigation are also those which are profitably irrigated (cabbage, cucumbers, potatoes, carrots, tomatoes, snap beans, sweet corn, beets). Many of them are also high-cost crops, in which a crop failure is the more serious because much has already been invested in the crop.

When the net returns to irrigation per acre are weighted roughly in proportion to acreages irrigated in Maryland in 1959 and averaged for all crops, the mean net return to irrigation is about $150 per acre. The practice of irrigation can be said to have been worth at least $1 1/4 million in revenues to Eastern Shore farmers in 1959 - or it can be said that they used about $1 1/4 million worth of water.

The per unit value of the water cannot be made precise because it is not known how much of the water was actually reserved for irrigation use. If water is stored to anticipate the season, a larger total quantity is set aside to allow for drought hazard and pond evaporation. When water is pumped directly as required during drought, a smaller total quantity is used, and the unit value appears higher. The true value probably lies somewhere between these two extremes: at one extreme, if all farmers had stored an acre-foot of water for each acre irrigated, the water would have been worth about

$150 per acre-foot or $12.50 per acre-inch or $0.46 per thousand gallons. If at the other extreme little water was stored, and consumption was about 6 acre-inches per acre, to allow for the application of 4.2 inches to the root zone and some evaporation and inefficiency, water would have been worth about $300 per acre-foot or $25 per acre-inch or $0.92 per thousand gallons. The value for individual farms certainly varies even more widely than the $150 to $300 limits suggested here; but on the whole these values are much higher than in most forms of dry-land irrigation.

The increasing population in the nearby metropolitan areas, better highways for the Eastern Shore, a rising standard of living, and the food habits associated with it, suggest a continuing strong market for the irrigated fresh-market vegetable and fruit crops of this area.

A number of other crops are irrigated on a smaller scale in the State, and the trend is still more difficult to evaluate. Farmers who have irrigation systems in order to irrigate their fresh-market crops often irrigate incidentally their process crops such as lima beans, sweet corn, peas and beans for the freezing and canning plants. The increased yield of these crops pays for the operating costs of irrigation but would not pay the fixed costs; that is, they do not alone make it worthwhile to invest in an irrigation system. This may change. Processors prefer the irrigated crops in quality. The processing companies themselves own farms on which they irrigate greens, in order to assure the timing of the earliest harvests of the season, to utilize their plant to capacity for as long a season as possible. Processing is a very sensitive market, changing rapidly in response to costs; its use of irrigation has grown from nothing to thousands of acres in the past ten years and may well increase. However, the returns per acre will be lower than for fresh-market crops.

Returns do not now appear to justify irrigation of field corn, soybeans, and pasturelands on the whole, except incidentally where the system is used part of the time for higher-value crops. The irrigation of tobacco is still experimental, and the results show small net returns if any. Tobacco is an acreage-allotment crop and the market is not likely to improve. All these expectations are reflected in the County Committee estimates of principal crops which will be irrigated in 1975 (Table 7, column 3). At costs and returns characteristic of 1963, irrigation at that scale in 1975 would represent a total net return to farmers of $8 million.

D. Maryland irrigation in the future

1. Previous estimates of irrigation expansion

Three different sets of estimates have previously been devised which apply to Maryland. First is the set of County Committee estimates; these were organized by the Agricultural Extension Service at College Park and published as part of the Irrigation Survey of 1959. The predictions are for the year 1975, and they are based on the assumption that the crops which it is profitable to irrigate now will be the same in the future; they take into account expected changes in acreages of various crops. They are the soundest possible basis for prediction, and are accepted here as our preferred estimates for 1980.

The second set of estimates, for 1980 and 2000, are the Kerr Committee Report estimates, based on a concept of food requirements; they assume that food production of the nation will be distributed geographically in the future in the same way that it is now. Irrigation needs were calculated to provide desired yields after cropland acreages were estimated. The Kerr

TABLE 7

Irrigation Data by Crops, 1959 Survey, Maryland

	(1)	(2)	(3)	(4)	(5)
Truck[a]	88,711	7,894	31,445	3.7	3.6
Field corn	459,000	617	16,611	4.4	4.6
Tobacco	39,600	555	4,350	-	2.4
Hay	408,500	377	5,810	4.6	5.2
Other		185	2,700	5.5	4.9
Total cropland	1,450,000	9,628	60,916	3.8	3.7
Orchard	No data	1,695	6,255	2.9	5.1
Nursery	"	406	3,095	7.3	9.7
Golf courses	"	200	1,810	-	7.4
Pasture	781,500	782	8,830	4.0	4.9
Total (or average)		12,711	80,906	3.85	4.215

[a] Including potatoes, sweet corn, and strawberries

(1) Acreage harvested 1959 (Maryland Census of Agriculture by counties)

(2) Acreage irrigated 1959 (1959 Irrigation Survey)

(3) Irrigated acreage forecast 1975 (County Committee estimates)

(4) Average application to root-zone, inches per acre, Eastern Shore, 1959

(5) Average application to root-zone, inches per acre, Maryland State, 1959

Committee Report's medium estimate for irrigation in the entire Chesapeake Bay Area is slightly smaller than the County Committee estimates for Maryland alone (1975-1980). The Kerr Committee study estimates that for low population levels of 2000, 13 percent of cropland will be irrigated, and for medium population levels, 65 percent of cropland. The County Committee estimates, and the present trend and returns calculated, suggest that the low estimates of the Kerr Committee are probably too low.

Estimates for some counties in Maryland were made for the Potomac River Basin Study.[4] The projection is for an average increase of irrigated acreage of about 3 percent from 1957 through 2010. This applies to the Piedmont and to Southern Maryland, but not to the Eastern Shore. Table 8 shows the acreages of irrigable land estimated in that study, together with the acreage irrigated in 1959 (very small). It also shows projections for 1980 and 2010 at the 3 percent rate, although such a mechanical application is not advised in the Potomac Study and provides rather wild estimates.

The procedure used in the Potomac Basin Study differs from that used in this chapter in several respects: (a) Potomac Basin irrigation requirements and profitability are based on the extreme droughts which occur one year in ten. Larger requirements are implied than in our study; the irrigation (Shore-type) discussed here produces benefits eight or nine years out of ten, and does not require a water supply sufficient for the driest year in ten to make it a profitable practice. (b) The Potomac Basin Study estimated available supply of water from streamflows only; this can be supplemented by groundwater supplies in Southern Maryland as well as the Eastern Shore.

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4. "Future Irrigation Development in the Potomac River Basin," Gary C. Taylor, U.S. Department of Agriculture, Agricultural Research Service, July, 1960.

TABLE 8

Potomac River Basin Counties, Irrigable and Irrigated Acreages

County	(1)	(2)	(3)	(4)	(5)
Charles	5,660	58	92	171	405
St. Mary's	5,220	30	58	108	255
Allegany	11,490	30	133	247	585
Frederick	43,660	656	323	601	1,421
Washington	37,600	2,446	1,626	3,024	7,154
Carroll	16,610	586	117	218	515
Montgomery	22,570	652	202	376	889
Prince George's	1,720	243	215	400	946

(1) Acres of irrigable land, as calculated by Potomac River Basin Study, land less than 3,000 feet horizontal distance or 60 feet vertical distance from a permanent stream

(2) Acreage irrigated 1957 (Survey)

(3) Acreage irrigated 1959 (Survey)

(4) Acreage irrigated 1980, projected at 3 percent annual rate of increase from 1959

(5) Acreage irrigated 2010, projected as in (4).

(c) The available supply was estimated at one-half of mean low flow; the arbitrary cutoff has an awkward legal basis. (d) The Potomac Basin Study concluded that future irrigation development in the region will have serious impact on the future water supply situation. This, however, appears to be true only if an unlimited supply is provided at less than cost, and if costs of supply at various locations and dates are not allowed to influence the profitability of irrigation.

However, the general conclusions about expansion of irrigation as stated below do not conflict with Potomac Basin estimates, and the latter are secondary to the more important question of irrigation on the Eastern Shore.

The three sets of estimates and other observations suggest adoption of the following expectations: after 1975 irrigation will probably not increase greatly in the counties of Southern Maryland (Region I), nor in Frederick and Washington Counties (Region II) and Cecil County: the refinement of irrigation for frost protection and fruit crops should be accomplished by 1975, and no great changes should occur thereafter; in Regions III and IV, nursery crops, lawns, cemeteries, and suburban irrigation will be the principal irrigators and will use water from municipal systems. Development of irrigation agriculture after 1975 can be expected to occur almost exclusively on the Eastern Shore. Projections of withdrawals and consumptive uses are presented in Table 9, where total annual uses have been averaged only over the 120-day irrigation season to represent peak use rates.

However, such estimates, especially of Eastern Shore expansion, contain a large element of uncertainty. The topography is favorable over a vast part of the Shore. Estimates of soil-types for potentially irrigable and potentially drainable cropland represent an extreme upper limit. Some extreme

TABLE 9

Projected Agricultural Water Withdrawals and Consumption, by Region, 1970-2010

Uses averaged over 120 day season	1959	1970			1980			2010		
		Low	Medium	High	Low	Medium	High	Low	Medium	High
Region I										
% of cropland irrigated	0.19%	0.35%	1.35%	1.46%	0.60%	1.01%	11.90%	1.45%	13.04%	28.99%
Acres of cropland irrigated	180	308	1,187	1,282	500	8,500	10,000	1,000	9,000	20,000
Withdrawals (000 gals/day)	326	558	2,149	2,320	905	15,388	18,103	1,810	16,293	36,206
Consumptive use (000 gals/day)	293	502	1,934	2,088	815	13,849	16,293	1,629	14,664	32,585
Region II										
% of cropland irrigated	0.79%	1.21%	1.86%	2.15%	1.67%	4.07%	5.56%	3.24%	4.86%	10.12%
Acres of cropland irrigated	2,318	3,420	5,242	6,066	4,500	11,000	15,000	8,000	12,000	25,000
Withdrawals (000 gals/day)	4,196	6,191	9,490	10,981	8,146	19,913	27,155	14,482	21,724	45,258
Consumptive use (000 gals/day)	3,776	5,572	8,541	9,883	7,331	17,922	24,440	13,034	19,552	40,732
Region III										
% of cropland irrigated	0.54%	.85%	1.42%	1.60%	1.27%	3.39%	4.24%	5.11%	5.84%	14.60%
Acres of cropland irrigated	1,601	2,215	3,731	4,179	3,000	8,000	10,000	7,000	8,000	20,000
Withdrawals (000 gals/day)	2,898	4,010	6,754	7,566	5,431	14,482	18,103	12,672	14,482	36,206
Consumptive use (000 gals/day)	2,608	3,609	6,079	6,809	4,888	13,034	16,293	11,405	13,034	32,585

(Continued on next page)

TABLE 9

Projected Agricultural Water Withdrawals and Consumption, by Region, 1970-2010

Uses averaged over 120 day season	1959	1970			1980			2010		
		Low	Medium	High	Low	Medium	High	Low	Medium	High
Region IV										
% of cropland irrigated	.45%	.57%	.65%	.80%	.71%	.91%	1.36%	20%	30%	40%?
Acres of cropland irrigated	417	579	660	816	780	1,000	1,500	1,000	1,500	2,000
Withdrawals (000 gals/day)	755	1,049	1,194	1,477	1,412	1,810	2,716	1,810	2,716	3,621
Consumptive use (000 gals/day)	680	944	1,075	1,329	1,271	1,629	2,444	1,629	2,444	3,259
Region V										
% of cropland irrigated	1.22%	2.46%	3.43%	4.39%	4.40%	8.06%	14.66%	7.87%	14.31%	28.61%
Acres of cropland irrigated	8,195	16,662	23,237	29,721	30,000	55,000	100,000	55,000	100,000	200,000
Withdrawals (000 gals/day)	14,835	30,163	42,066	53,804	54,310	99,567	181,030	99,567	181,030	362,060
Consumptive use (000 gals/day)	13,352	27,147	37,859	48,424	48,879	89,610	162,927	89,610	162,927	325,854
Maryland Total										
%of cropland irrigated	0.87%	1.66%	2.48%	3.21%	2.97%	6.40%	10.47%	6.65%	12.05%	24.65%
Acres of cropland irrigated	12,711	22,793	34,065	44,064	38,780	83,500	136,500	72,000	130,500	267,000
Withdrawals (000 gals/day)	23,010	41,262	61,668	79,769	70,203	151,160	247,106	130,342	236,244	483,350
Consumptive use (000 gals/day)	20,700	37,136	55,501	71,792	63,183	136,044	222,395	117,308	212,620	435,015

estimates are presented in the next section, which will demonstrate the problem which might arise by 2010.

2. Extreme use rates

The calculations in this section are designed to show the amounts of water which would be consumed in agriculture under the most extreme assumptions of abundant water, high-value crops, large acreages, etc. These are conceivable although not probable, and are treated as high estimates for the year 2010.

If all harvested cropland in the Eastern Shore counties (excluding Cecil County) were irrigated, if harvested cropland were approximately the same as at present (614,000 acres), if one-half the land were double-cropped (therefore 921,000 acres of crops to irrigate), and if one acre-foot of water were stored for each acre to be irrigated, the amount of water reserved annually for this use would be 921,000 acre-feet. This represents a use of 300 billion gallons annually, or 822 m.g.d. throughout the year, the equivalent of a very large industrial city.

If water were not stored on a long-term basis, but drawn largely from superficial groundwater recharge, we would assume that one-half that amount of water, or 6 acre-inches per acre, would be taken. Consumption would be 460,000 acre-feet or 150 billion gallons annually, but the characteristic seasonal demand would represent a much more serious drain on water resources. If this demand were distributed over a four-month growing season of 120 days, it would amount to 1,250 m.g.d. average, or if it were distributed over a 30-day period of drought, it would represent 5,000 m.g.d. However, the consumption use rate of the Maryland Irrigation Guide (1955) of .15 to .2 inch per day indicates a conceivable peak water consumption rate for 614,000 acres during a widespread drought at about 3,300 m.g.d. This is the physical limit which could be applied and evaporated if there were no rain.

Such extreme estimates, while indicating the potential maximum magnitude of agricultural uses, are not a reasonable basis for projection, even over a fifty-year period. These extreme use levels would far exceed all foreseeable supply of water for the Eastern Shore, and would be attainable only in the event of massive technological changes (say, in desalinization) or an equally massive reallocation of national resources toward food production.

3. Irrigation supply on the Eastern Shore

Thus far, the chief sources for irrigation-water on the Eastern Shore have been dug ponds, small springs, and streams from which water is diverted in time of high flow and stored in special farm ponds. These are waters supplied by local precipitation on the Shore, and during periods of low precipitation all these sources are diminished. They are not related to the abundant deep aquifers. The demand for irrigation-water from sources of this type is not likely to affect the availability of water for municipal and industrial uses, because these central systems use deep wells for a supply of better and more uniform quality and higher rates of withdrawal. The deeper aquifers are supplied from rainfall in the central and western parts of the State and are not vulnerable to lessened infiltration or runoff which local drought-irrigation practice may cause on the Shore. The groundwater reservoirs do not fluctuate as streamflow does. (Their level has an annual cycle.)

If shallow sources of the type now used were relied upon for great expansion of irrigation beyond the estimates of 53,000 acres in 1975, we could expect low flows of streams on the Eastern Shore to be diminished. The chief conflict would be the use of streams for handling of wastes. In order to minimize this conflict, farmers must use high-flow streamwater and store it. The present law assures that they do not use streams at low flow, but it does not clearly restrain use of springs and groundwater infiltration-recharge, a portion of which would otherwise flow to streams, maintaining their low flow.

There is reason to think, however, that this problem will not materialize. First, the possibility for groundwater recharge is localized, and those sites have been developed earliest as cheap sources of water for irrigation; this source cannot be expanded indefinitely. Second, excessive demand on surface or local groundwater for irrigation will probably be reflected in lower water tables, and under these conditions, the chances of the farmer losing his recharge-water supply are greater than the chances of the farmer's slow recharge diminishing the supply in streams. Third, we project nearly one hundred percent of municipal and industrial wastes (after treatment) to be discharged to salt or brackish water by 2010.

If, indeed, irrigation develops by 2010 to some 50 to 80 percent of flat low-lying cropland, the only possible reliable supply is deep wells. The cost thus far has generally appeared too great, but irrigation can expand to that extent only if it becomes profitable for farmers to pump from deep wells. If deep wells do come into use for this purpose, the systems would be large, and the water available in large supply. Systems would be dispersed and should not cause mutual interference. They would be subject to the same permit regulations as other deep wells. Demand on deep wells represents annual storage, and from the point of view of alternative uses, deep wells are the ideal way to distribute the peak demand for irrigation-water over the year; they would not diminish local streamflow which would remain plentiful for limited waste dilution purposes.

In summary, the evidence suggests that as irrigation develops to the levels projected for 1975, it will not conflict with other uses; the development of irrigation beyond that level will be slowed or restricted until it becomes sufficiently profitable to pay for deep-well supply: evidence further indicates that deep-well supplies are adequate, and when irrigation demand is distributed in this way by the natural underground storage system, the annual consumption will not be such as to conflict with any other uses.

4. Piedmont irrigation supply

The use of irrigation in the Piedmont counties provides a smaller return and is less attractive, because the heavier soils retain water longer, crops suffer from drought only in exceptional years, and pasture land is available for dairying, so that irrigation is not the cheapest way to provide additional forage. Little land is level enough for cheap and efficient distribution of water to fields. Farmers experimented with irrigation in the Piedmont in the 1950's, and many stopped and sold their equipment to Eastern Shore irrigators.[5]

For the fruit crops grown in Frederick and Washington Counties, irrigation systems are attractive for frost protection, a demand which does not occur at seasons of critical low flows; this should present no problem of long-run conflict.

In cases where supplemental irrigation is profitable for cool-weather vegetables, tomatoes and potatoes in the Piedmont, water supply could

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5. See Maryland Irrigation Survey Results for the Crop Year of 1959, Including Estimates by County Committees for the Year 1975, Paul M. Galbreath, University of Maryland, February, 1960.

ultimately become a problem. Unlike the high water tables and abundant groundwater of the Eastern Shore, Piedmont water supply consists almost entirely of streamflow, and development of supplies is by means of large-scale projects. Our projections to 2010 do not indicate overall shortages, although localized conflicts could occur.

E. Summary

The agricultural demands for water and the problems created by changing land use differ greatly in four areas in Maryland: the Eastern Shore, the Western and Piedmont regions, the metropolitan areas, and the Southern counties.

The Eastern Shore population is relatively stable, agricultural production is highly specialized, and the demand for water for irrigation is increasing and will continue to increase rapidly. By 1975 surface water supplies will have been developed at the cheaper sites. However, a vast groundwater supply or natural reservoir is available, and after 1975 the farmers can be expected to continue to adopt irrigation to the extent that returns cover the costs of utilizing the deep-well supply. On the whole, this large development of irrigation can take place through individual decision and risk and with the technical cooperation of the agricultural agencies, without creating any special hazards of pollution or shortage to public, industrial or recreational interests.

In the Piedmont and Western Maryland, water supplies are limited, but the value of irrigation for dairy and fruit farming on these soils is also limited. Population changes are expected to be modest. The development of irrigation will be much slower, more highly localized, and governed by the legal arrangements and public policies for the use and payment for stored water or controlled streamflow.

In the metropolitan regions around Baltimore and Washington, D.C., farming is intensive and irrigation is practiced, but its development is limited by the rapid removal of land from agriculture to intensive urban and suburban uses. In this region the serious water problems which changing land use will produce are storm drainage and pollution of shallow wells and streams.

In Southern Maryland, the supply of groundwater is extensive, although stream supply is often unsatisfactory for irrigation purposes. The value of irrigation in tobacco farming is very uncertain at this time. The higher costs and lower and more uncertain returns have limited irrigation in the past, but after 1975 it is quite possible that the rural economy of the southern counties may come to resemble that of the Eastern Shore in many ways, and irrigation may develop on a large scale later.

In practically all parts of the State, large numbers of rural dwellers can expect to abandon shallow wells because of pollution or failure in drought, and to invest more in deep wells and domestic purification systems.

CHAPTER VI

RECREATION

A. Introduction

The purpose of this Chapter is to present our analysis and projections of water use for recreational purposes. Detailed consideration of recreation is justified partly by the complexity of the relationship between water use and recreation, and partly by the phenomenal growth of participation in a wide variety of recreational activities that has been observed since World War II, and which has been widely predicted for the future.

Economically, recreation is one of a large number of groups of consumer goods and services among which households have to allocate their time and expenditure. Unlike many commodities, it is intangible, and is therefore placed in the category of "services" along with education, medical services, shoe shines and many other items of everyday consumption. The study of demand and supply in any service category is plagued by the notorious difficulty of defining exactly what the product is. The difficulty is no less with recreation than with medical or educational services. In all such cases the economist is driven to the use of indices - such as the number of doctor visits or the number of years of education completed - which, it is hoped, at least partly quantify the product in question. The usual indices used to measure the consumption of recreation are number of visits, number of visitor days or number of participations in the recreational activity.

All commodities, tangible and intangible, are produced with the aid of certain inputs. Most kinds of recreational services are produced with a variety of inputs drawn from the traditional categories of land, labor and capital. Water is used as one input in a wide range of recreational services. The ways in which water is used are complex and varied, however, and a number of distinctions must be kept in mind.

One major distinction is that between on-site and withdrawal uses. Many kinds of recreational activities entail the use of water-on-site, i.e., without removing it from its natural location. Boating, fishing, swimming, skin diving and water-skiing are examples. Indeed, there are very few forms of outdoor recreation whose value is not enhanced by the presence of bodies of water. Most typical state-park activities, such as hiking, picnicking and camping, are more enjoyable if participated in near water. Of course, the presence of bodies of water is one of the major criteria for the location of state parks. Other recreational activities, such as swimming in artificial pools, involve withdrawal of water from its natural location. These uses are analogous to the other withdrawal uses studied in the previous three chapters.

Another major distinction is that between quantity and quality requirements. Quantities withdrawn are small for most recreational activities, the major exception being artificial swimming pools. This category introduces no new conceptual problems, and estimates and projections are presented in Section D. Quantity requirements are also imposed by on-site uses in that there must be sufficient water in the stream or lake to carry on the activity in question. However, the usual way of maintaining high stream quality, (and the way analyzed in subsequent chapters in this report), is a combination of waste treatment before discharge into streams and low-flow augmentation of reservoir construction. Therefore, policies designed to meet quality requirements result in increased flows during the summer months when most on-site recreational activities take place. The result is that it is almost inevitable that a flow sufficient to meet quality requirements will also be sufficient to meet quantity requirements. In addition, the reservoirs themselves provide excellent areas for on-site recreational activities.

The foregoing implies that the major water problem for on-site recreational activities is the quality of water in lakes and streams. It is on this issue that most of the uncertainty and controversy concerning stream pollution must focus. There are really two questions to be answered. First, what are the quality requirements for specific recreational activities? Second, for what recreational activities should stream quality be sufficiently high?

A reasonably precise answer can be given to the first question. Acceptable quality standards exist for a wide variety of recreational activities.[1] Water quality is a multi-dimensional concept and is discussed in detail in Chapter VII. Here, it is sufficient to point out that the measure of quality that is most useful for a wide variety of purposes, including those of this report, is the number of parts per million of dissolved oxygen. Of all recreational uses, swimming, skin diving and water-skiing impose the most stringent quality requirements on water used. For these purposes, many dimensions of water quality are relevant and the appropriate standard is similar to that for drinking water.[2] For boating, and to provide habitats for a variety of fresh water fish, dissolved oxygen levels between 3 and 5 p.p.m. are required.[3] In addition, partly for aesthetic reasons, water should be free of offensive solids, odors and colors.

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[1] See Water for Recreation - Values and Opportunities, Study Report 10, Chapter 2, Outdoor Recreation Resources Review Commission (designated ORRRC throughout the remainder of this study), Washington, 1962. This report is one of twenty-seven such reports under the parent title Outdoor Recreation for America which are of inestimable value to the study of outdoor recreation.

[2] ORRRC Study Report 10, p. 17.

The second question is more difficult to answer. The ideal procedure would be to ascertain the dollar value that residents would place on increased aesthetic and recreational benefits resulting from increases in stream quality, then calculate the increased costs of treatment and storage that would be required to achieve these increases in quality. We could then conclude that increases were desirable up to the point at which benefits no longer exceeded costs. In fact, however, no one knows the value of increased stream quality. The cost side is discussed further in subsequent chapters where estimates of the costs of meeting certain quality standards are presented.

In principle it would be possible, using the procedures followed in subsequent chapters, to calculate the cost of raising the quality of the typical Maryland stream to swimming pool standards. We have not made these calculations, however, partly because they would be time-consuming and expensive. In addition, it seems apparent that the cost of meeting this quality standard would be prohibitively high. In the coming decades, fresh-water lakes and streams of sufficient quality for swimming will almost certainly have to be restricted to certain park-like areas in which water quality is carefully protected for recreational purposes in much the same way that water quality is now protected in streams that are used to supply drinking water. There are now a number of such areas and it is important that they be preserved and extended.

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3. ORRRC Study Report 10, pp. 17-18.

For the typical Maryland stream, we have chosen quality levels on which to base our cost calculations in the following way: Many of these streams, such as the Patapsco, Patuxent, Monocacy and other rivers, either flow through some of the most popular Maryland state parks or provide the best locations for future state parks that are accessible from major population centers. In fact, state parks on a number of these streams are now in the planning stage. In these areas, the appropriate water quality standard is that which is adequate for recreational activities that are typically carried on in state parks such as picnicking, hiking, camping, fishing and boating. For boating and fishing, a dissolved oxygen content between 3 and 5 p.p.m. was quoted as the appropriate standard, and this range undoubtedly suffices as an appropriate standard for the other activities mentioned. For some of these activities, however, water quality is of mainly aesthetic importance, which introduces a subjective element into the determination of quality standards. For that reason, it is important to present water resource development programs for several quality levels. This will be undertaken in Chapter X. The water quality standards chosen will be those appearing plausible on the basis of the considerations introduced in this paragraph.

The remaining sections of this Chapter are concerned with estimates and projections of demands for recreational facilities in which specific water-related recreational activities take place. In recent years, great interest has developed in the economics of outdoor recreation.[4] This interest has been excited, we have said, by the recent dramatic growth of participation in many forms of outdoor recreation and by the widespread feeling that future demands will require drastic increases in the resources devoted to recreation.

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[4] The study of outdoor recreation has benefited greatly from recent publications of Resources for the Future. See especially: Land for the Future, Chapter III, by M. Clawson, R. Held, and C. Stoddard, Johns Hopkins Press, 1960; Resources in America's Future, Chapter XI, by H. Landsberg, L. Fischman, and J. Fisher, Johns Hopkins Press, 1963. These, and the ORRRC reports, are highly useful sources.

RFF has employed a threefold classification of recreational activities and facilities which has proven useful for many purposes and will be employed in the following pages. At one extreme are user-oriented activities and facilities, which are constructed to be close to users and are located almost independently of the presence of water on other national amenities. Examples of these are golf courses, swimming pools, tennis courts, parks, playgrounds and zoos. At the other extreme are resource-oriented activities and facilities, located where outstanding resources are found. Typical of such facilities are mountains, major lakes, and seashore areas. They are often national parks or forests, sometimes state parks or forests. Assateague is probably the only remaining potential resource-oriented facility in Maryland. Between these two extremes are the intermediate activities and facilities, which are located partly with reference to the availability of desirable natural resources and partly in response to the recreational needs of a substantial body of nearby residents. Rivers, lakes, reservoirs and hilly or rocky terrain are potential intermediate recreational sites. Most state parks and forests and some private parks belong to this category.

The remaining sections of this Chapter are devoted to present and future demand and supply conditions for some of these recreational activities and facilities. As was suggested above, Assateague is probably the only remaining undeveloped resource-oriented area in Maryland. Therefore, attention is focused on intermediate and user-oriented facilities in the following sections. Section B discusses intermediate facilities. Section C is concerned with user-oriented facilities. Section D is devoted to swimming pools, the only recreational facility for which withdrawal uses are substantial.

B. Intermediate recreational facilities

The first task in analyzing the demand for and supply of intermediate recreation is to decide what facilities are to be included under this heading. In almost all their work, Clawson, Held and Stoddard restrict themselves to consideration of state parks and T.V.A., Corps of Engineers and Bureau of Reclamation reservoirs as intermediate facilities. The reason for this restriction is presumably the lack of readily available data for other kinds of facilities. But several other categories of recreational facilities clearly come under the definition that they give of intermediate facilities. In particular, wildlife refuges and state forests should obviously be included. We have been able to obtain some data for six categories of intermediate recreational facilities in Maryland. Data on numbers of facilities, acreage and acreage per capita are presented in Table 1. In all cases, the acreage figures include only those areas available for at least some kinds of recreation. This entails the exclusion of substantial areas administered by the State Fish and Game Agency. The only questionable areas included in the table are about 5,000 acres of land administered by the National Park Service and located along several parkways in Maryland. Roadside picnicking is about the only recreational activity that takes place in these areas. The only intermediate recreational areas excluded from Table 1 are salt water beaches.

According to Table 1, about a quarter of a million acres, or 4 percent of the land area, is devoted to intermediate recreational facilities in Maryland. About half of this area is in seven state forests, about 10 percent is

TABLE 1

Intermediate Recreational Facilities in Maryland, 1962

Region	State Fish and Game Agency				State Parks			
	No.	Acres	Acres per 1000 regional population	Acres per 1000 State population	No.	Acres	Acres per 1000 regional population	Acres per 1000 State population
I - Southern Md.	4	761	8.74	0.24	1	333	3.83	0.11
II - Western Md.	20	16,077	18.46	5.18	8	8,215	30.65	2.77
III - Baltimore Metro.	9	1,172	.65	.37	4	6,328	3.51	2.40
IV - Washington Metro.	8	4,456	6.38	1.44	1	305	.44	0.10
V - Eastern Shore	19	20,543	84.19	6.62	2	6,585	26.99	2.12
Maryland	60	43,009	13.87	-	16	21,766	7.49	-
	State Forests				County and Local Areas			
I - Southern Md.	2	4,984	57.29	1.61	0	0	-	-
II - Western Md.	4	97,895	36.53	31.57	2	6,638	24.77	2.14
III - Baltimore Metro.	0	0	-	-	1	392	.217	.126
IV - Washington Metro.	0	0	-	-	0	0	-	-
V - Eastern Shore	1	12,251	50.21	5.23	1	4	.016	.0013
Maryland	7	115,130	38.41	-	4	7,034	2.27	-

(continued on next page)

TABLE 1

Intermediate Recreational Facilities in Maryland, 1962

	U.S. Fish and Wildlife Refuges				National Park Service Facilities			
Region	No.	Acres	Acres per 1000 regional population	Acres per 1000 State population	No.	Acres	Acres per 1000 regional population	Acres per 1000 State population
I - Southern Md.	1	2,679	30.79	.86	0	0	-	-
II - Western Md.	0	0	-	-	3	5,941	22.17	1.92
III - Baltimore Metro.	1	4	.015	.0013	2	2,932	1.63	.946
IV - Washington Metro.	0	0	-	-	4	12,491	17.9	4.03
V - Eastern Shore	3	14,116	57.85	-	0	0	-	-
Maryland	5	16,799	5.41	-	9	21,364	6.89	-

	Totals			
I - Southern Md.	8	8,757	100.65	2.82
II - Western Md.	37	134,766	50.28	43.45
III - Baltimore Metro.	17	10,828	6.00	3.49
IV - Washington Metro.	13	17,252	24.71	5.56
V - Eastern Shore	26	53,499	76.64	17.25
Maryland	101	225,102	-	72.57

Source: Unpublished data, Department of Forests and Parks in state parks, almost 20 percent is in State Fish and Game Agency areas (mostly wildlife management areas), about 10 percent is in National Park Service facilities, and somewhat less than 10 percent is in U.S. Fish and Wildlife Refuges. The disparity between the location of population and recreational areas has been widely observed nationally and is repeated within the State. As shown in Table 1, 80 percent of the State's intermediate facilities are located in Western Maryland and the Eastern Shore, whereas these areas contain only one-sixth of the State's population.

Unfortunately, attendance data are not available for all the facilities listed in Table 1. From some attendance data presented in ORRRC Study Print No. 1, it can be inferred that for the country as a whole about 1.7 visits per capita were made to facilities of this sort in 1960. If that figure is applied to Maryland's population, it implies about 5.25 million visits to Maryland facilities in 1960, a figure not out of line with some fragmentary attendance data presented below.

For Maryland we have detailed attendance data for state parks and forests. These data are summarized in Table 2 for all the years for which they are available. The most striking characteristic of these figures is the rapid rise in the total to a peak in 1958, followed by a decline to 1961 and a moderate increase in 1962. This pattern is completely out of line with trends in almost all kinds of recreation in almost all parts of the country. It seems likely that some of these figures are inaccurate. The recent figures, however, are probably accurate since collection procedures have improved in the last few years. If only the 1947 and 1962 figures are used, a 250 percent decade rate of growth is implied. This astronomical rate of growth should not be extrapolated mechanically into the distant future, but

TABLE 2

Attendance Maryland State Parks and Forests

1947, 1950-1962

(000)

	Parks	Forests	Total
1947	446.7	211.4	658.1
1950	498.9	200.3	699.1
1951	846.5	287.2	1,133.8
1952	823.6	336.2	1,159.8
1953	1,462.1	412.1	1,874.3
1954	1,932.7	522.2	2,454.9
1955	1,826.1	514.8	2,340.0
1956	2,881.2	505.4	3,386.6
1957	3,327.0	674.2	4,001.2
1958	5,079.6	589.4	5,669.1
1959	4,708.8	601.4	5,310.2
1960	3,263.7	549.8	3,813.4
1961	2,766.4	455.0	3,222.3
1962	3,089.3	512.0	3,602.1

Source: Unpublished data, Department of Forests and Parks.

it is not far out of line with national trends. The comparable figure for the country as a whole is 200 percent. Considering Maryland's rapid population growth since 1947, its rapid growth of state park and forest visits is not unreasonable.

Among the intermediate recreational facilities shown in Table 1, only attendance data for state parks are adequate to permit comparisons among states. This is not, however, so serious a limitation as it appears, since the vast majority of visits to intermediate facilities are to state parks. In Maryland, Table 2 shows that there is now about one visit per capita per year to state parks. For the country as a whole, Table 4, below, shows that the figure is 1.5. These figures are about 60 percent and 90 percent respectively of the 1.7 visits per capita to all intermediate facilities. Thus, attendance figures for state parks are broadly indicative of visits to all intermediate facilities. A regional breakdown of Maryland state park (and forest) attendance in 1962 is presented in Table 3.

The pattern is one that should be expected. The most intensively used parks are those near the major population centers, whereas the parks located in more distant parts of the State are used at low intensity. Thus, attendance per acre is highest for parks in the Baltimore Region, next highest in Southern Maryland, and lowest in Western Maryland and on the Eastern Shore. (This comparison ignores the Washington Region which contains only one rather lightly used state park, Seneca Creek, of 305 acres.) The data for the Baltimore Region are heavily influenced by Patapsco State Park, which received half the visitors to all state parks in 1962, and had the most intensive use of any state park, 376 visits per acre.

The 1961 data for state park visits for the country as a whole and for

TABLE 3

State Parks and State Forests: Attendance and Acreage, 1962

Region	No.	Total Attend.	Attend. per 1000 regional residents	Attend. per 1000 State residents	Attend. per acre
			State Parks		
I - Southern Md.	1	10,130	116.4	3.27	304.2
II - Western Md.	8	531,503	1,983.22	171.40	64.69
III - Baltimore Metro.	4	2,291,944	1,270.48	739.10	362.20
IV - Washington Metro.	1	3,335	4.78	1.08	10.93
V - Eastern Shore	1	252,348	1,034.21	81.38	38.41
Maryland	15	3,089,260	-	996.21	195.05
			State Forests		
I - Southern Md.	2	76,217	876.06	24.58	15.29
II - Western Md.	4	375,011	1,399.30	120.93	3.83
III - Baltimore Metro.	0	0	0	0	0
IV - Washington Metro.	0	0	0	0	0
V - Eastern Shore	1	61,615	252.52	19.87	5.03
Maryland	7	512,843	-	165.35	.224

Source: Unpublished data, Department of Forests and Parks other Eastern states are presented in Table 4. Several comments are required concerning these data. First, over 40 percent of all the state park acreage in the country is in New York State. Over 90 percent of the New York acreage consists of the entire land area in 15 forest preserve counties. Second, except for New York, the acreage per capita is much higher for the country as a whole than for any Eastern state. This reflects the fact that most of the acreage for all outdoor recreational facilities is located in the midwestern prairie and Rocky Mountain states. Third, except for New York, Virginia and West Virginia, state parks in the densely populated East are much more intensively used than in the country as a whole. Delaware, New Jersey, Ohio, Connecticut, and Pennsylvania, in that order, have higher attendance per acre than Maryland. Thus, in comparison with other Eastern states, Maryland state parks are not intensively used, although they are in comparison with the country as a whole. Fourth, in attendance per capita Maryland ranks below the national average and below most of the other Eastern states. Fifth, there is some tendency for states with intensive salt water beaches to have a small number of acres per capita of state parks. Care is needed in this comparison, however, since some states have salt water beaches which are state parks. Nevertheless, the tendency is strong for salt water beaches to be municipal or private. It is not coincidental that, except for New York, the states with the highest acreage per capita in Table 4 (West Virginia, Pennsylvania, and Ohio) are the only states with no salt water shoreline. Excepting New York, Maryland has more acres per capita of state parks than the average of the states in the table with extensive shoreline.

Predicting the future demand for recreation is an extremely difficult and tricky business. Mechanical extrapolation into the future of trends from

TABLE 4

State Park Attendance and Acreage, 1961

United States and Selected Eastern States

Area	Population (C00)	Attendance (000)	Acreage (000)	Attend. per acre	Attend. per cap.	Acre per 1000 pop.
United States	179,323	273,484	5,799.1	47.1	1.5	32.3
Connecticut	2,535	4,789	22.2	215.5	1.9	8.8
Delaware	446	601	1.2	518.9	1.3	2.7
Maryland	3,101	3,091	23.9	129.4	1.0	7.7
New Jersey	6,067	6,320	22.7	278.0	1.0	3.7
New York	16,782	35,518	2,567.3	13.8	2.1	153.0
Ohio	9,706	21,311	90.0	236.7	2.2	9.3
Pennsylvania	11,319	23,450	167.3	140.2	2.1	14.8
Virginia	3,967	1,112	29.9	37.2	0.3	7.5
West Virginia	1,860	1,922	44.4	43.3	1.0	23.9

Source: State Park Statistics, National Park Service.

the last twenty-five years leads to astronomical projections. On the other hand, plausible extrapolations of income, leisure and travel persuade most specialists that recreation will continue to grow very rapidly during the coming decades. During the last few years, three sets of comprehensive long-run projections of the demand for recreation have appeared.[5] Projections for state park attendance for the country as a whole from the two RFF studies, along with our projections for Maryland, are summarized in Table 5. Clawson, Held and Stoddard project a ten-fold increase in per capita state park visits by 2000. Most specialists regard this figure as too high, and the later RFF study projects a five-fold increase (from 1.5 to 8.4). ORRRC do not project state park attendance, but they project a doubling of per capita visits to national parks and of per capita participation in most major recreational categories by 2000. Thus, the ORRRC projections are much more conservative than the RFF projections, and the consensus is, apparently, that they are too low.

This report's projection of per capita state park visits for 2000 is slightly more conservative than the lower of the two RFF national projections. We assume 8 visits per capita to Maryland state parks by 2000, whereas Clawson, Held and Stoddard assume 15 and Landsberg, Fischman and Fisher assume 8.4. Partly, this is because Maryland starts from a smaller base of per capita visits than does the country as a whole (1.0 as compared with 1.5). As was stated above, this partly reflects the greater attractiveness of salt water facilities in Maryland than in the country as a whole. Since

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[5] Land for the Future, Ch. III, Clawson, Held and Stoddard.
Resources in America's Future, Ch. XI, Landsberg, Fischman and Fisher.
ORRRC Study Report 26.

TABLE 5

State Park Projections

1961 Actual, Projected 1980-2010

	Visits per Capita			Visits per acre			1961 - Actual Acreage 1980-2010 - Adequate Acreage (000 Acres)		
	Clawson, Held, Stoddard	Landsberg, Fischman, Fisher	Md. Water Study	Clawson, Held, Stoddard	Landsberg, Fischman, Fisher	Md. Water Study	Clawson, Held, Stoddard	Landsberg, Fischman, Fisher	Md. Water Study
1961	1.5	1.5	1.0	47.1	47.1	129.4	5,799	5,799	18.1
1980		3.5	4.0		70.0	170.0		12,000	108.8
2000	15.0	8.4	8.0	70	100.0	200.0	50,000	28,000	259.2
2010			10.0			210.0			355.0

this attractiveness is already reflected in the 1961 figures, there is no reason to believe that the percentage growth of Maryland state park attendance will be much less than the similar figure for the country as a whole. Therefore, we have assumed almost as rapid a rate of growth of per capita Maryland state park visits as Clawson, Held and Stoddard do of state park visits in the country as a whole. (Clawson, Held and Stoddard assume a ten-fold increase from 1960 to 2000. We assume a ten-fold increase only by 2010, and from a smaller base.)

It is equally difficult to ascertain a reasonable figure for visits per acre. More intensive development and use of existing sites is a direct alternative to further land acquisition. Since land values at appropriate sites are increasing more rapidly than development costs, it follows that more intensive development will be desirable in the future than has been in the past. There is, however, a limit to this process, since intensive development changes the nature of the recreational experience. For these reasons we have assumed a modest increase in annual visits per acre from about 130 in 1961 to 210 in 2010. The increase is slightly more rapid during the earlier decades when population is projected to grow more rapidly than toward the end of the century. The intensity figures we have assumed are two to three times those considered adequate by RFF. On the other hand, it can be seen from Table 4 that our assumed 210 visits per acre in 2010 is below the current annual visits per acre in Connecticut, New Jersey, Delaware and Ohio. With appropriate development, there is no reason to believe that use at the levels of intensity we have assumed will impair the recreational value of Maryland state parks.

Even with these rather conservative assumptions, Table 5 indicates the need for vast increases in the acreage of Maryland state parks. Roughly, the 2010 figure of 355,000 acres is compounded from a 150 percent population growth (medium forecast), a ten-fold increase in per capita state park visits, and a 60 percent increase in visits per acre. The result is an increase of almost 20 times in adequate acreage.

More perspective can be gained on this problem if reference is made back to Table 1. There it was shown that there are now about 225,000 acres of public intermediate recreational facilities in Maryland. If that figure were compared with the figure of 355,000 acres required by 2010 in Table 5, the increase would seem much more modest. Of course, these figures are not strictly comparable. The attendance figures have referred only to state parks and have excluded unknown, but probably small, attendance figures for other intermediate recreational facilities. It is clear that many of the other facilities in Table 1 are potentially able to support much more intensive recreational use than they do at present. This is particularly true of state forests, which constitute over half the total acreage of intermediate facilities in the State at present. The 1961 total acreage of state parks and forests was about 136,000, substantially more than the adequate acreage figure of 109,000 given in Table 5 for 1980. To develop all state forests for the 210 visits per acre per year assumed in Table 5 for state parks would involve a definite alteration in the recreational experience and such a course of action is not recommended. Nevertheless, more intensive use of other facilities is the only alternative to a vast expansion of state park facilities if projected demands are to be met. Even if other facilities are developed for much more intensive use, a large expansion of state park acreage will still be needed. For example, assume that in 2010 there are 100 visits per acre to all intermediate facilities now in the State other than state parks. (This is an enormous increase over the 0.224 visits per acre of state forests in 1962 recorded in Table 3.) Then we would still need almost 240,000 acres of state parks in 2010, a ten-fold increase over current acreage.

Finally, it should be said in this connection that the acreage of Maryland state parks is now expanding very rapidly. The reported acreage grew by a third between 1960 and 1961. According to a recent report of the Baltimore Regional Planning Council,[6] there are plans to enlarge the state parks by some 27,000 acres by 1980, which would more than double their present size. Furthermore, most of these planned acquisitions are quite near the major population centers and include substantial bodies of water. (The major areas are near Liberty Reservoir, Soldiers Delight, and on the Patuxent, Patapsco, Gunpowder and Susquehanna Rivers.) These acquisitions will bring the area of Maryland state parks to about 50,000 acres by 1980. This is about half the adequate acreage projected for 1980 in Table 5. Therefore, if severe overcrowding of state parks is to be avoided, either much more land must be acquired or a program of intensive development must be undertaken to make accessible parts of state parks that are now little used.

In many parts of the country, reservoirs are major facilities for intermediate recreational activities. In Maryland, there is some water-related recreational activity on the three Baltimore water supply reservoirs and on the two Maryland reservoirs that supply water for the Washington, D.C. metropolitan area. The three Baltimore reservoirs and their controlled watersheds contain about 29,000 acres. The recreational use of these five reservoirs has increased in recent years, and careful consideration should be given to possible further recreational use.

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[6] Open Spaces, Technical Report No. 5, Baltimore Regional Planning Council, 1960.

Of even more importance are the reservoirs recommended in the recently-completed Corps of Engineers' Potomac River Basin Report.[7] The recreational potential of these reservoirs justifies detailed analysis of their effects on the acreage requirements that have been projected in this section.

Of the sixteen major reservoirs in the Corps of Engineers' recommended plan for the Potomac River Basin, seven are wholly or partly in Maryland. Pertinent recreational data for these reservoirs are summarized in Table 6. Three of the seven reservoirs are entirely in Maryland, and the other four are shared with other states in proportions shown in the second column. The acreage and visitation data shown in the rest of the table refer to Maryland portions of the reservoirs only. All projections in Table 6 are Corps of Engineers projections. Of course, some Maryland residents will use portions of the reservoirs in neighboring states and vice-versa. However, throughout this study of recreation, we have assumed that interstate visits to the facilities in question would continue at their current ratio to intrastate visits. In that case, total visits will bear a constant relation to Maryland population, and all projections can be in terms of Maryland population. This assumption justifies the mechanical split of the reservoir data between Maryland and neighboring states.

Column 4 shows the total Maryland portion of the reservoir's acreage, including land for reservoir construction and operation, recreation, and

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[7] Potomac River Basin Report, U.S. Army Corps of Engineers, February, 1963.

TABLE 6

Recreational Data

Proposed Corps of Engineers Reservoirs

(1) Project	(2) Location	(3) Completion Date	(4) Total Md. Acreage	(5) Md. Recreational Acreage	(6) Visitation (000) Initial	Ultimate
Bloomington	.5 Md. .5 W. Va.	1965	1,685	365	25	55
Six Bridge	Md.	1971	10,880	2,650	300	625
Seneca	.5 Md. .5 Va.	1977	35,610	6,850	1,500	3,750
Licking Creek	.2 Md. .8 Pa.	1987	1,428	692	55	148
Town Creek	Md.	1993	6,880	2,580	260	850
Savage II	Md.	1998	1,290	50	100	100
Tonoloway	.25 Md. .75 Pa.	2007	1,725	758	79	200

Source: Potomac River Basin Report, U.S. Army Corps of Engineers.

wildlife mitigation. Column 5 shows the number of acres to be set aside for recreation in Maryland for each reservoir. In column 6, initial visitation means the number of visitors projected for the fifth year after completion of the reservoir, and ultimate visitation means the number projected for the fiftieth year after completion.

Taking into account the projected completion dates in Table 6, it is possible to calculate total acreage and visitation date for Maryland reservoirs for each year until 2010. These calculations are summarized in Table 7. Linear interpolation has been used for years between "initial" and "ultimate" visitation levels.

TABLE 7

Aggregate Visitation and Acreage Data,Corps of Engineers Reservoirs in Maryland, Projected 1970-2010

	1970	1980	1990	2000	2010
Projected visitations (000)	25	1,863	2,439	3,457	4,194
Total acreage	1,685	48,175	49,603	57,773	59,498
Recreational acreage	365	9,865	10,557	13,187	13,945
Visitors per acre	14.8	38.7	49.2	59.8	70.5
Visitors per recreational acre	84.9	188.8	231.0	262.2	300.8

Source: Potomac River Basin Report, U.S. Army Corps of Engineers.

Table 7 also presents data on visits per acre. The last two rows of the table show the ratio of projected visits to total acres, and to acres set aside for recreational purposes. These figures are consistent with recent trends in visits to TVA and Corps of Engineers reservoirs. Visits per acre to Corps of Engineers reservoirs are typically somewhat lower than the corresponding figure for state parks. In Table 4 we indicated that 1961 visits per acre of state parks were 47.1 for the U.S. as a whole and 129.4 for Maryland. The 1961 figure for visits per acre to Corps of Engineers reservoirs was about 25. The projected visits per acre to Corps of Engineers reservoirs in Maryland start out below this figure and rise rapidly to 70.5 in the year 2010. This projected trend represents not only the anticipated increase in visits per capita to intermediate recreational facilities and anticipated population growth in Maryland, but also a gradual increase in public awareness of the recreational amenities available at Corps of Engineers reservoirs. The last row of Table 7 naturally indicates much more intensive use of areas set aside for recreational use. These figures are also consistent with experience in state parks and with recent trends in Corps of Engineers reservoir visits.

We must now ask what effect these projections will have on the acreage requirements indicated in Table 5. The relevant calculations are reported in Table 8. Row 1 shows the visits per capita to intermediate facilities that were projected in Table 5. Row 2 gives projected visits obtained by multiplying figures in row 1 by our medium population projections in Chapter III, Table 2. Row 3 gives the projected visits to Corps of Engineers reservoirs from Table 7. Row 4 gives the projected visits net of those to Corps of Engineers reservoirs. Dividing the figures in row 4 by the visits per acre figures in Table 5 gives us row 5, the acreage required for visits other than those to Corps of Engineers reservoirs. Figures in this row should be compared with the required acreage figures in Table 5.

TABLE 8

Adjusted Acreage Needs for Maryland State Parks, Projected 1970-2010

	1970	1980	2010
Visits per capita	2.0	4.0	10.0
Visits (000)	7,598	18,492	74,530
Visits to Corps of Engineers Reservoirs (000)	25	1,863	4,194
Visits net of Corps of Engineers Reservoirs visits (000)	7,573	16,629	70,336
Required acres	50,000	98,000	335,000

These calculations indicate that the Corps of Engineers' recommended plan would reduce the acreage required for Maryland state parks by about 10 percent in 1980. In addition to the Corps of Engineers reservoirs, about 98,000 acres of state park land would be required, in comparison with about 108,800 acres in the absence of the Corps of Engineers reservoirs. Beyond 1980, the percent of total need that will be supplied by Corps of Engineers reservoirs will fall. This is because the construction of reservoirs beyond that date will not keep pace with the growth of demand for intermediate recreational facilities. By 2000, Corps of Engineers reservoirs will permit a reduction from 259,000 to 242,000 in required state park acreage, or about 7 percent. By 2010, the figures will be 355,000 and 335,000, or about 6 percent.

We conclude as follows: The Corps of Engineers reservoirs will be a major addition to Maryland's intermediate recreational facilities if the recommended plan is carried out. However, they will represent a relatively small part of the vast increase in state park acreage that will be needed during the next fifty years.

C. User-oriented recreational facilities

As stated in Section B, user-oriented recreational facilities are those that are located primarily for accessibility in large population centers. Sites are chosen almost without regard to land and water resources. Hence, problems of user-oriented recreation are even less closely related to water supply and demand than are problems of intermediate recreation. Many city parks and playgrounds have no water facilities other than drinking fountains. Yet, like almost all forms of outdoor recreation, the value of the recreational experience is enhanced by the presence of bodies of water. Problems of user-oriented recreational facilities are almost entirely those of large urban centers. Hence, in this section, attention will be focused on Maryland's two large metropolitan centers.

Unfortunately, data on user-oriented facilities are extremely inadequate. Partly, this is because of the great diversity among facilities that fall under that heading. Partly, it is also because private facilities are extremely important in the user-oriented group, and data on private facilities are almost nonexistent. The procedure in this section is as follows: First, the only data available on a state-wide basis are presented. Second, a more detailed discussion is presented for the Baltimore Region. Fairly complete data for this region are available from a recent study by the Baltimore Regional Planning Council[8] and our data are almost all from that source. In

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[8] Open Spaces, Technical Report No. 5, Baltimore Regional Planning Council, 1960.

Section D, attention is focused on swimming pools, the one user-oriented facility that has a close relationship to water use.

In Land for the Future, Clawson, Held and Stoddard report acreage of municipal and county parks by state, in 1955, per 100 urban residents in 1950. The figure for Maryland is 0.64, the highest of any neighboring state. Figures for the United States and for several Eastern states are as follows:

United States	0.77
Connecticut	0.95
Delaware	0.47
Maryland	0.64
New Jersey	0.41
New York	0.43
Ohio	0.96
Pennsylvania	0.43
Virginia	0.33
West Virginia	0.57

A widely advocated standard for municipal and county parks is one acre per 100 urban residents. That standard is well above the U.S. average and, aside from Illinois, it was met by no highly urbanized state in the country in 1955. If it is accepted that the per capita figure cannot be expected to rise in Maryland, we might assume the maintenance of the present ratio of acres to urban population as a goal for the future. Using our projections of the urban population from Chapter III, Table 2, we get the following acreage requirements for the State. (Table 9 on next page.)

These figures imply a near-tripling of acreage during the half century, and even they will entail substantial increases in the intensity of use of municipal and county parks as visits per capita increase. However, increases in visits per capita to these facilities will probably be small compared with increases in other kinds of recreation. In addition, outside the large metropolitan areas, these facilities are probably not now used very intensively.

TABLE 9

Adequate Acreage for Maryland's Municipal and County Parks, 1960-2010

	Acres
1960	13,896
1970	18,236
1980	22,782
1990	27,326
2000	32,768
2010	38,159

It is near large population centers that the major problems of user-oriented recreation arise. We therefore turn to some figures for the Baltimore Region.

Table 10 summarizes data on user-oriented facilities for the Baltimore Region in 1960. Two comments are necessary on the construction of the table. First, all state parks and water-supply reservoirs are omitted since they have already been included in the intermediate category. However, they are to some extent substitutes for user-oriented facilities and will become better substitutes in the future as transportation improves. Second, schools and school playgrounds have been omitted. Many school playgrounds have considerable recreational value and the tendency is to construct new schools with more recreational area. However, in the most densely populated parts of the Region and particularly in Baltimore City, many schools have relatively little recreational area.

Table 10 shows that the Region as a whole has almost one acre of user-oriented recreation per 100 population. Roughly one-third of this acreage is

TABLE 10

User-Oriented Recreation Areas, Baltimore Region, 1960[1]

	Public				Private[3]		Total	
	Parks		Recreation Areas[2]					
	Acres	Acres per 100 pop.	Acres	Acres per 100 pop.	Acres	Acres per 100 pop.	Acres	Acres per 100 pop.
Baltimore City	3,921	0.42	766	0.08	350	0.04	5,037	0.54
Anne Arundel County	32	0.02	5	0.00	1,285	0.62	1,322	0.64
Baltimore County	365	0.07	205	0.04	3,834	0.78	4,404	0.89
Carroll County	44	0.08	8	0.02	665	1.26	717	1.36
Harford County	399	0.52	4	0.01	3,084	4.02	3,487	4.55
Howard County	0	0.0	7	0.02	1,076	2.97	1,083	2.99
Total	4,761	0.26	995	0.06	10,294	0.57	16,050	0.89

1. Acreage data taken from Open Spaces, Baltimore Regional Planning Council, 1960

2. Playgrounds, playfields, etc.

3. Game farms, hunt clubs, beaches, yacht clubs, swim clubs, camps, drive-in movies, country clubs, golf courses and ranges, sports arenas, miscellaneous

public and two-thirds private. Of the public facilities, most of the acreage is in parks. Of the private facilities, most of the acreage is in game farms and hunt clubs, camps, golf courses and country clubs. A large number of the facilities, though a small part of the acreage, are beaches and yacht and boat clubs on the Chesapeake. For these facilities, acreage is a misleading measure of recreational value.

The most striking characteristic of the data in Table 10 is the virtual absence of public facilities outside Baltimore City. To some extent this is explained by the fact that large parts of the five counties included in the table are not urbanized. To some extent it is also explained by the lower density of suburban areas and by the growing tendency to provide some recreational area in housing and apartment developments. Nevertheless, the absence of proximate public recreational areas is now a problem in many densely-settled suburban areas, and will become a much bigger problem in the coming decades as these counties continue their burgeoning growth. Howard County, for example, has only seven acres of public user-oriented recreational area. Indeed, half of the total user-oriented area in that county is taken up by two large private golf courses.

Because of the variation of population density, and of types of facilities included, realistic standards are difficult to set for user-oriented facilities. For the country as a whole, Clawson, Held and Stoddard project a rise in annual per capita visits to user-oriented facilities from 6 in 1956 to 15 in 2000. They argue that one acre of park land and playground should be provided per 100 population. This figure would entail a reduction by one-half of the visits per acre by 2000. The present level is 1,500, which would be reduced to less than 800 if their standard were met. This standard is clearly unrealistic for large urban centers, and in our calculations we have used a standard of one-half acre each of public and private facilities per 100 population. Using the Clawson, Held and Stoddard projection of visits per capita and our medium population projection for the Region, this standard would result in a slight rise in visits per acre during the half-century. The implied acreages are in Table 11.

TABLE 11

Adequate Acreage, User-Oriented Recreational Facilities, Baltimore Region, 1960 Actual, Projected 2010

	Public	Private	Total
1960 Actual	5,756	10,294	16,050
1960 Adequate	9,020	9,020	18,040
1970	10,565	10,565	21,130
1980	12,710	12,710	25,420
1990	14,780	14,780	29,500
2000	17,335	17,335	34,670
2010	19,945	19,945	39,890

Table 11 indicates a need for a doubling of the acreage of public facilities by 1970 and a further doubling by 2010. Private facilities are adequate for the present population by the standard used, but will have to be doubled by 2010.

D. Swimming pools

The final recreational facility to be considered in this Chapter is swimming pools. Of all the user-oriented recreational facilities, swimming pools are the most obviously water-related. However, not all swimming facilities are included in this discussion. Salt water beaches are either resource-oriented or intermediate areas. Furthermore, fresh-water swimming in natural water bodies, in artificial lakes and in quarries is excluded from the data to be presented below. Such facilities ought properly to be included under the intermediate category and, indeed, many of them are located in the state parks and forests. Man-made swimming pools, on the other hand, can be located wherever there is relatively flat, well-drained land and an adequate supply of pure water. They therefore come under the user-oriented heading.

Data have been collected from the Baltimore City and State Health Departments on the number and capacity of swimming pools in Baltimore City and in each county.[9] All public pools are included and all private pools except those located in single family residences. Included are pools in schools, parks, country clubs, swimming clubs, motels, apartments, housing developments, camps, YMCAs, etc. In Baltimore City, many of the pools are public. Outside the City, almost all are private. The data are summarized in Table 12.

TABLE 12

Maryland Swimming Pools, 1962

Region	No. of Pools	Gallons Capacity (000)	Gal. Cap. per Regional Res.
I - Southern Md.	25	1,967	22.6
II - Western Md.	46	9,316	34.8
III - Baltimore Metro.	221	30,646	17.0
IV - Washington Metro.	191	33,278	47.7
V - Eastern Shore	82	7,073	29.0
Maryland	565	82,280	26.5

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[9] Capacity data are unavailable for some pools. Where necessary, capacity has been estimated by taking the average capacity of the pools of known capacity in the county and applying it to pools whose capacity is unknown.

The Baltimore Region has the largest number of pools, but the lowest gallons of capacity per capita figure. The Washington, D.C. Region has the most gallons of capacity per capita, followed by Western Maryland, the Eastern Shore, Southern Maryland, and the Baltimore Region in that order. In Western Maryland, Southern Maryland, and the Eastern Shore, capacity is concentrated in tourist facilities such as motels; in the Baltimore and Washington Regions, capacity is concentrated in public facilities and private facilities, such as country clubs, that are mainly used by the local population.

There are also available some limited attendance figures for Baltimore City. From these can be made a crude estimate of attendance for the State as a whole. In 1962, attendance for several indoor pools in Baltimore averaged 0.35 persons per year per gallon of pool capacity; attendance at several outdoor pools averaged 0.10 persons per year per gallon of capacity. If we apply these ratios to the total capacity of indoor and outdoor pools in the City, we obtain an estimate of attendance for the City as a whole. For the counties, a breakdown between indoor and outdoor pools is not available. However, the percentage of pool capacity which is in indoor pools is very small - much smaller than in the City (most of the indoor pools in Baltimore City are in public schools and very few public schools have pools outside the City). Also, it is likely that pools are used less intensively outside the City than inside. It therefore seems reasonable to apply the ratio for outdoor pools in Baltimore City to the capacity of all pools in the rest of the State. This procedure leads to the estimates of attendance shown in Table 13.

TABLE 13

Estimated Attendance at Maryland Swimming Pools, 1962

Region	Estimated Attendance	Estimated Attendance per Regional Resident
I - Southern Md.	196,700	2.26
II - Western Md.	931,600	3.48
III - Baltimore Metro.	3,634,000	2.01
IV - Washington Metro.	3,327,800	4.77
V - Eastern Shore	707,300	2.90
Maryland	8,797,400	2.84

For the State as a whole, these estimates indicate almost three visits per capita per year. This figure can be compared with an ORRRC (Study Print No. 26) estimate of about four swimming "occasions" per capita for the entire country in 1960. Since the ORRRC figure includes all swimming occasions, whereas ours refers only to swimming in pools, we would expect theirs to be somewhat higher than ours. Within the State, visits per capita are smallest in the Baltimore Region, highest in the Washington Region.

Some limited data are also available on water intake in a few pools served by the Baltimore municipal water supply system. The data are meter readings collected from the Bureau of Water Supply. Certain pool-related water uses - such as showers, sanitary facilities, etc. - are included. Unfortunately, the meter readings include unknown amounts of water for purposes unrelated to swimming in addition to pool and pool-related water uses. For example, one of the meters served a drive-in movie and a snack bar in addition to a large swimming pool. The data available showed water use in six outdoor pools during a period of four years. Making a rough allowance for water use not related to pools, we estimate that on the average these pools used about 3.0 gallons of water per gallon of capacity during a year.

Applying this figure to the capacity estimates in Table 12, yields the estimates of water use for Maryland swimming pools that are shown in Table 14.

TABLE 14

Estimated Water Intake in Maryland Swimming Pools, 1962

Region	Intake (000)
I - Southern Md.	5,901
II - Western Md.	27,948
III - Baltimore Metro.	91,938
IV - Washington Metro.	99,834
V - Eastern Shore	21,219
Maryland	246,840

Projections of future swimming pool use are complicated by the availability of other swimming facilities. On the one hand are the extensive salt and natural fresh water facilities available in Maryland. As indicated in Section A, the supply of natural fresh-water swimming facilities is not likely to grow substantially in the coming decades. Concerning salt water facilities, it must be remembered that the current figures already reflect the effect of their availability. However, it is likely that salt water swimming will increase more than pool swimming in the future just because the demand for intermediate recreation is likely to grow more than the demand for user-oriented recreation. On the other hand is the burgeoning demand for "back-yard" swimming pools, increased use of which is obviously a substitute for use of pools included in our survey. In view of these factors it seems reasonable to adopt the estimate made by ORRRC of a doubling of per capita swimming "occasions" by 2000.

To estimate the water that will be withdrawn for swimming pools in the future, we can start from the 1962 data quoted above. Combining the estimate of three gallons of water used per gallon of capacity with the estimate of 0.1 visitors per gallon of capacity, we estimate 30 gallons of water used per swimming pool visitor. Improvement in filter design and more intensive pool use will undoubtedly tend to reduce this figure somewhat. More intensive pool use reduces the water withdrawal per person because it spreads over more visitors the water lost by draining the pool at the end of the season. On the other hand, the use of water for pool-related activities will probably grow during the coming decades. Probably, more pools will have showers, snack bars, etc. We assume that these two effects will approximately cancel and therefore assume a withdrawal of 30 gallons per swimmer in our projections. The results of these calculations are shown in Table 15. For the State as a whole, the table indicates almost 50 million visits in 2010, or about six per capita per year. The projected water use for swimming pools in that year is nearly 1.4 billion gallons. The variation in attendance and water use from region to region is accounted for partly by variation in projected population, and partly by variation in projected participation rates.

The final task in this section is to estimate the part of withdrawals for swimming pools that will be consumed. The first thing to note is that, in Regions III and IV, almost all withdrawals for swimming pools are from municipal water supply systems, and this is likely to continue to be true in the future. Therefore, swimming pool withdrawals in these Regions are already included in the projections of non-industrial withdrawals from municipal systems in Chapter III, Table 4. Thus, no separate figure for water consumption from swimming pool use needs to be calculated for these two Regions. In Regions I and V, withdrawals for swimming pools are mostly from private wells. Furthermore, just as with municipal withdrawals in these

TABLE 15

Projected Swimming Pool Attendance and Water Use, 1970-2010

	Region I		Region II		Region III	
Year	Attendance	Water use	Attendance	Water use	Attendance	Water use
1970	322	9,660	1,227	36,810	5,283	158,490
1980	483	14,490	1,622	48,660	7,626	228,780
1990	700	21,000	2,122	63,660	10,346	310,380
2000	990	29,700	2,765	82,950	13,868	416,040
2010	1,249	37,470	3,147	94,410	16,953	508,590

	Region IV		Region V		Totals	
1970	6,036	181,080	1,016	30,480	13,884	416,520
1980	9,379	281,370	1,409	42,270	20,519	615,570
1990	13,629	408,870	1,869	56,070	28,666	859,980
2000	18,905	567,150	2,448	73,440	38,976	1,169,280
2010	22,474	674,220	2,900	87,000	46,723	1,364,220

Attendance: thousands of visitors per year

Water use: thousands of gallons per year

Regions, most of the discharge is likely to be to saline bodies. Therefore, it is assumed that all withdrawals in these Regions are consumptive. In Region II, some withdrawals for swimming pools are from public and some from private sources. Consumption results from evaporation, leakage, splashout, and from discharge after the end of the summer season. We estimate that withdrawals are about 50 percent consumptive in that Region.

These considerations lead to the consumption projections shown in Table 16. High and low consumption projections were obtained exactly as were the medium projections, except that the high and low population projections from Chapter II, Table 2 were used.

TABLE 16

Water Consumption in Swimming Pools, 1960-2010

Region	1960	1970	1980	2010
		High		
I - Southern Md.	75	114	181	565
II - Western Md.	180	215	300	714
III - Baltimore Metro.	-	-	-	-
IV - Washington Metro.	-	-	-	-
V - Eastern Shore	300	354	524	1,313
Maryland	555	683	1,005	2,592
		Medium		
I - Southern Md.	75	108	162	416
II - Western Md.	180	205	270	525
III - Baltimore Metro.	-	-	-	-
IV - Washington Metro.	-	-	-	-
V - Eastern Shore	300	339	470	967
Maryland	555	652	902	1,908
		Low		
I - Southern Md.	75	104	149	315
II - Western Md.	180	198	248	399
III - Baltimore Metro.	-	-	-	-
IV - Washington Metro.	-	-	-	-
V - Eastern Shore	300	326	432	731
Maryland	555	628	829	1,445

CHAPTER VII

STREAMFLOW REQUIREMENTS FOR QUALITY MAINTENANCE

A. Introduction

Central to the usefulness of water in most of its uses is its quality. While we have termed quality a "dimension" of water supply in Chapter I, quality is itself really a set of dimensions or characteristics. In the Kerr Committee study,[1] water pollutants were classified under eight categories:

1. Sewage and other oxygen-demanding wastes
2. Infectious agents (bacteria, parasites, etc.)
3. Plant nutrients (phosphates, nitrates)
4. Organic chemical exotics (pharmaceuticals, insecticides, etc.)
5. Other mineral and chemical substances (detergents, salts, etc.)
6. Sediments (silt, mud, etc.)
7. Radioactive substances
8. Heat

In this report our analysis is primarily of the first of these waste categories, commonly termed biochemical oxygen demand (BOD). There are several reasons for confining our estimates of quality maintenance flow requirements to those needed to achieve acceptable levels of BOD and dissolved oxygen: First, in the cases of infectious agents, many organic and other chemicals, and radioactive substances, increased streamflow cannot be expected to alleviate pollution problems, since even very small quantities tend to have cumulative toxic effects; second, infectious agents can be controlled to a high degree with present processes and at reasonable costs; third, suspended sediments may even be increased with higher streamflows; and, fourth, available evidence suggests that the flows required for assimilation of oxygen-demanding wastes exceed those which would be needed to dilute dissolved salts or chemicals.[2] The remaining pollution category, plant nutrients, is closely related to oxygen demand, since its primary effect is to promote the growth of algae whose death and decay creates secondary oxygen demand.

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[1] Kerr Committee Report, Print No. 9.

The measure of quality used throughout the rest of this report (and to which we have alluded briefly in the chapter on recreation) is the amount of dissolved oxygen (DO) remaining in streams after assimilation of wastes; this is expressed in parts per million. Considerably more discussion of the assimilation process is given later in this chapter. At this point it is important to emphasize that the choice of a particular dissolved oxygen standard for streams (or set of standards for different streams) is a matter of public policy, and not a technical issue. As the previous chapter pointed out, on-site recreational uses and general aesthetic considerations require that streams be clean - but how clean? We attempt in a later chapter to give the costs of achieving various dissolved oxygen minima, in order to make possible more informed public decisions on this extremely important issue.[3]

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2. Kerr Committee Report, Print No. 29.
3. See Kerr Committee Report, Nos. 9 and 29, also Water Supply-Economics, Technology and Policy, J. Hirschleifer, J. C. De Haven and J. W. Milliman, University of Chicago Press, 1960 and Water Pollution: Economic Aspects and Research Needs, Allen V. Kneese, Johns Hopkins Press, 1962.

While it is the purpose of this Chapter to assess streamflow requirements for quality maintenance, this cannot be done without analysis of the relation between waste treatment and streamflow requirements, since these are substitutes in the achievement of stream quality standards. As will be emphasized later on, there are substantial gaps in existing technical knowledge on stream assimilation capacities, particularly when we try to deal with whole river systems or regional aggregates of separate streams. Nevertheless, the public does have a large area of discretion in arriving at policies for required treatment levels and the provision of adequate streamflow, and once again an attempt is made to provide relevant information for such decisions.

Section B of this Chapter estimates the present and expected amounts of wastes generated by regional populations and industries, and makes assumptions for 1970, 1980, and 2010 as to the water bodies to which residual wastes (after treatment at specified levels) will be discharged. Section C discusses the problems of evaluating the effects of oxygen-demanding wastes on streams, and Section D estimates the future streamflow requirements by region, using three alternative estimates of assimilation capacity.

B. Waste production and disposal

The unit in which the biochemical oxygen demand of wastes is often measured is the "population equivalent" - the average oxygen demand exerted upon receiving waters by the sewage and related wastes of one person.[4] The wastes of small industries and commercial establishments are included

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[4] This, in fact, is not a constant value, but differs over time, and from place to place. One source gives a median value of about 0.21 lbs. of oxygen demand, with extremes of 0.08 and 0.40 lbs. (Patuxent Regional Sewerage Report, Wolman, Geyer and Beavin, Baltimore, 1961.) We use a value of 0.24 in this report. (This is 5-day B.O.D. at 20° C.)

TABLE 1

Derivation of Waste Loadings; Medium Projection
Region I, Southern Maryland

	1970	1980	2010
Regional population	111,000 persons	138,000 persons	262,000 persons
Projected employment, selected industries			
20-Food processing	1,400 "	1,700 "	2,600 "
26-Pulp and paper	0 "	0 "	100 "
28-Chemicals	100 "	200 "	200 "
29-Petroleum products	100 "	100 "	200 "
33-Primary metals	0 "	0 "	0 "
Industrial waste per employee			
20-Food processing	52 p.e.	60 p.e.	95 p.e.
26-Pulp and paper	100 "	140 "	250 "
28-Chemicals	44 "	59 "	167 "
29-Petroleum products	30 "	37 "	111 "
33-Primary metals	5 "	5 "	10 "
Industrial wastes produced			
20-Food processing	72,800 p.e.	102,000 p.e.	247,000 p.e.
26-Pulp and paper	--	--	25,000 "
28-Chemicals	4,400 "	11,800 "	33,400 "
29-Petroleum products	3,000 "	3,700 "	22,200 "
33-Primary metals	--	--	--
Total industrial	80,200 "	117,500 "	327,600 "
Municipal wastes	111,000 "	138,000 "	262,000 "
Total all wastes produced	191,200 "	255,500 "	589,600 "
Low treatment levels	75%	80%	90%
LOW TREATMENT WASTES DISCHARGED	47,800 p.e.	51,100 p.e.	58,960 p.e.
High treatment levels	80%	95%	95%
HIGH TREATMENT WASTES DISCHARGED	38,240 p.e.	12,775 p.e.	29,480 p.e.

TABLE 2

Derivation of Waste Loadings, Medium Projection
Region II, Western Maryland

	1970	1980	2010
North of Potomac -			
Maryland population-Potomac Watershed in Region	271,500 persons	297,500 persons	417,800 persons
Pennsylvania population-Potomac Watershed	141,200 "	158,700 "	223,000 "
Total population	412,700 "	456,200 "	640,800 "
Projected Maryland employment, selected industries			
20-Food processing	2,200 "	2,300 "	3,100 "
26-Pulp and paper	2,200 "	2,400 "	3,700 "
28-Chemicals	500 "	800 "	900 "
33-Primary metals	200 "	200 "	200 "
Industrial waste per employee			
20-Food processing	52 p.e.	60 p.e.	95 p.e.
26-Pulp and paper	200 "	276 "	525 "
28-Chemicals	44 "	59 "	167 "
33-Primary metals	5 "	5 "	10 "
Municipal wastes (row 3 x 1.0)	412,700 "	456,200 "	640,800 "
Maryland industrial wastes produced			
20-Food processing	114,400 "	138,000 "	294,500 "
26-Pulp and paper	440,000 "	662,400 "	1,942,500 "
28-Chemicals	22,000 "	47,200 "	150,300 "
33-Primary metals	1,000 "	1,000 "	2,000 "
Total	577,400 "	848,600 "	2,389,300 "
Estimated Pennsylvania industrial wastes produced (row 2 x 1.0)	141,200 "	158,700 "	223,000 "
Total all wastes produced	1,131,300 "	1,463,500 "	3,253,100 "
Low treatment levels	75%	80%	90%
LOW TREATMENT WASTES DISCHARGED	282,825 "	292,700 "	325,310 "
High treatment levels	80%	95%	95%
HIGH TREATMENT WASTES DISCHARGED	226,260 "	73,175 "	162,655 "
South of Potomac -			
Southern Potomac drainage population	372,100 persons	419,700 persons	605,415 persons
Southern Potomac drainage municipal wastes	372,100 p.e.	419,700 p.e.	605,415 p.e.
Southern Potomac drainage industrial wastes	372,100 "	419,700 "	605,415 "
Total waste produced	744,200 "	839,400 "	1,210,830 "
LOW TREATMENT WASTES DISCHARGED	186,050 "	167,880 "	121,083 "
HIGH TREATMENT WASTES DISCHARGED	148,840 "	41,970 "	60,542 "
Ohio Basin Portion -			
Population	10,400 persons	12,000 persons	15,000 persons
Municipal wastes produced	10,400 p.e.	12,000 p.e.	15,000 p.e.
LOW TREATMENT WASTES DISCHARGED	2,600 "	2,400 "	1,500 "
HIGH TREATMENT WASTES DISCHARGED	2,080 "	600 "	750 "

TABLE 3

Derivation of Waste Loadings, Medium Projection
Region III, Baltimore Metropolitan Area

	1970	1980	2010
Regional population	2,113,000 persons	2,542,000 persons	3,989,000 persons
Projected employment selected industries			
20-Food processing	23,300 "	24,300 "	25,000 "
26-Pulp and paper	6,800 "	8,100 "	12,300 "
28-Chemicals	17,600 "	18,500 "	21,700 "
29-Petroleum and products	1,000 "	1,200 "	1,600 "
33-Primary metals	39,800 "	42,800 "	43,900 "
Industrial waste per employee			
20-Food processing	52 p.e.	60 p.e.	95 p.e.
26-Pulp and paper	100 "	140 "	250 "
28-Chemicals	44 "	59 "	167 "
29-Petroleum and products	30 "	37 "	111 "
33-Primary metals	5 "	5 "	10 "
Industrial wastes produced			
20-Food processing	1,211,600 "	1,458,000 "	2,375,000 "
26-Pulp and paper	680,000 "	1,134,000 "	3,075,000 "
28-Chemicals	774,400 "	1,091,500 "	3,623,900 "
29-Petroleum and products	30,000 "	44,400 "	177,600 "
33-Primary metals	199,000 "	214,000 "	439,000 "
Total Industrial	2,895,000 "	3,941,900 "	9,690,500 "
Municipal wastes	2,113,000 "	2,542,000 "	3,989,000 "
Total all wastes produced	5,008,000 "	6,483,900 "	13,679,500 "
Low treatment levels	75%	80%	90%
LOW TREATMENT WASTES DISCHARGED	1,252,000 p.e.	1,620,975 p.e.	1,367,950 p.e.
High treatment levels	80%	95%	95%
HIGH TREATMENT WASTES DISCHARGED	1,001,600 p.e.	405,244 p.e.	683,975 p.e.

TABLE 4

Derivation of Waste Loadings, Medium Projection
Region IV, Washington Metropolitan Area

	1970	1980	2010
Regional population	1,023,000 persons	1,321,000 persons	2,305,000 persons
Projected employment, selected industries			
20-Food processing	2,700 "	3,000 "	3,200 "
26-Pulp and paper	400 "	500 "	900 "
28-Chemicals	3,300 "	3,500 "	3,500 "
29-Petroleum products	300 "	300 "	500 "
33-Primary metals	100 "	100 "	100 "
Industrial waste per employee			
20-Food processing	52 p.e.	60 p.e.	95 p.e.
26-Pulp and paper	100 "	140 "	250 "
28-Chemicals	44 "	59 "	167 "
29-Petroleum products	30 "	37 "	111 "
33-Primary metals	5 "	5 "	10 "
Industrial wastes produced			
20-Food processing	140,400 p.e.	180,000 p.e.	304,000 p.e.
26-Pulp and paper	40,000 "	70,000 "	225,000 "
28-Chemicals	145,200 "	206,500 "	584,500 "
29-Petroleum products	9,000 "	11,100 "	55,500 "
33-Primary metals	500 "	500 "	1,000 "
Total industrial	335,100 "	468,100 "	1,170,000 "
Municipal wastes	1,023,000 "	1,321,000 "	2,305,000 "
Total all wastes produced, Maryland	1,358,100 "	1,789,100 "	3,475,000 "
Low treatment levels	75%	80%	90%
LOW TREATMENT WASTES DISCHARGED	339,525 p.e.	357,620 p.e.	347,500 p.e.
High treatment levels	80%	95%	95%
HIGH TREATMENT WASTES DISCHARGED	271,620 p.e.	89,455 p.e.	173,750 p.e.
District of Columbia and Virginia wastes produced	1,475,780 "	1,686,060 "	2,505,000 "
Low treatment wastes discharged	368,945 "	337,212 "	250,500 "
High treatment wastes discharged	295,156 "	84,303 "	125,250 "

TABLE 5

Derivation of Waste Loadings, Medium Projection Region V, Eastern Shore

	1970		1980		2010	
Regional population	271,000	persons	313,000	persons	464,000	persons
Projected employment, selected industries						
20-Food processing	13,500	"	14,600	"	16,700	"
26-Pulp and paper	200	"	200	"	400	"
28-Chemicals	2,100	"	2,500	"	2,800	"
29-Petroleum products	0	"	0	"	100	"
33-Primary metals	100	"	100	"	100	"
Industrial waste per employee						
20-Food processing	52	p.e.	60	p.e.	95	p.e.
26-Pulp and paper	100	"	140	"	250	"
28-Chemicals	44	"	59	"	167	"
29-Petroleum products	30	"	37	"	111	"
33-Primary metals	5	"	5	"	10	"
Industrial wastes produced						
20-Food processing	702,000	"	876,000	"	1,586,500	"
26-Pulp and paper	20,000	"	28,000	"	100,000	"
28-Chemicals	92,400	"	147,500	"	467,600	"
29-Petroleum products	--		--		11,100	"
33-Primary metals	500	"	500	"	1,000	"
Total industrial	814,900	"	1,052,000	"	2,166,200	"
Municipal wastes	271,000	"	313,000	"	464,000	"
Total all wastes produced	1,085,900	"	1,365,000	"	2,630,200	"
Low treatment levels	75%		80%		90%	
LOW TREATMENT WASTES DISCHARGED	271,475	p.e.	273,000	p.e.	263,020	p.e.
High treatment levels	80%		95%		95%	
HIGH TREATMENT WASTES DISCHARGED	217,180	p.e.	68,250	p.e.	131,510	p.e.

in this concept as they are normally disposed of through municipal sewage systems. We can therefore estimate a large part of future waste output directly from projected populations. This is shown in Tables 1 to 5 in the first rows.

The only complicating factor in the calculation of municipal wastes is the necessity in Region II of estimating the contribution to these wastes by population outside of Maryland, but within the Potomac watershed. Since population projections have not been made for these areas in Pennsylvania, Virginia, and West Virginia, it is assumed that their future populations will stand in the same ratio to the Maryland projections as the ratios of the respective projected populations in the U. S. Commerce Department Potomac Study Report.[5] It is further assumed that total industrial wastes will be equal to municipal wastes for areas outside of Maryland.

Certain large industries also produce oxygen-demanding wastes in great quantities. This is true in particular of industries which process animal or plant resources - food processing (slaughtering, canning, dairies), paper pulp and soap manufacture, and early stages of textile processing - and also of the chemical and petroleum refining industries. Of these industries, food processing is widely spread throughout Maryland, with concentrations present and projected for the future in the Eastern Shore and Western Maryland (Regions V and II). Paper pulp manufacture occurs on a large scale only in Western Maryland, but paper products are also made elsewhere, particularly in the Baltimore Metropolitan area (Region III).

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[5] U. S. Corps of Engineers Study, Vol. IX.

We have projected the increasing output of chemicals not only in the Baltimore area (where it is already important), but also in the other Regions on tidewater (especially Regions I and V). A similar, though smaller, increase and spread of petroleum refining is projected by the year 2010. See Chapter II, Tables 11 to 13.

Tables 1 to 5 record projected employment for each of the high-pollution industries by Region. To calculate BOD waste production in these industries, however, we need an estimate of waste output per employee and we need to project this output to 1970, 1980, and 2010. There are few data from which to estimate even the present level of waste per employee, and even fewer on which to base judgements as to the trends to be expected in the future. It is very likely, therefore, that estimates in this section will be improved in the future when more data have become available for analysis; in the meantime, we lean heavily on a few sources of information.[6] In order to add municipal and industrial wastes, we express industrial wastes also in terms of population equivalents.

The per employee wastes for 1954 shown in Table 6 result from dividing estimates of total wastes by industry[7] by total employment by industry taken from the United States Census of Manufactures, 1954. Projections to 1980 and 2010 were made by multiplying the 1954 waste per employee by the

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[6] See Industrial Wastes - Their Disposal and Treatment, Willem Rudolfs (ed.), American Chemical Society Monograph #118, Reinhold Publishing Company, New York, 1953. Also see Kerr Committee Report, Print No. 9 and Unpublished Manuscript by Nathaniel Wollman.

[7] Nathaniel Wollman, Unpublished Manuscript, based on Rudolfs (op. cit.).

If we assume, as has been suggested by R. L. O'Connell, that the Rudolfs data are based on a p. e. of .167 lbs., our estimates of industrial wastes should be reduced by nearly one-third.

TABLE 6

Calculation of Waste Production Per Employee

	Level				Rate of Change (per cent)	
	1954	1980	2000	2010	1954-1980	1954-2010
Waste Production (million p.e.)						
20-Food	72.6	137.4	213.6	252	89%	247%
26-Paper	59.3	188.6	364.7	460	218	676
28-Chemical	21.5	108.6	268.1	347	405	1515
29 Petroleum	4.4	9.2	16.5	20	109	359
Output (index)						
20-Food	100	194	313	372	94%	272%
26-Paper	100	268	550	691	168	591
28-Chemicals	100	510	1254	1626	410	1526
29-Petroleum	100	221	416	513	121	413
Ratio of Rates of Change					Ratios (Rate of Waste Change)/(Rate of Output Change)	
20-Food					.948	.910
26-Paper					1.297	1.144
28-Chemicals					.987	.993
29-Petroleum					.900	.870
Rate of Change - Output/Worker					1954-1980	1954-2010
20-Food					42.5%	136.2%
26-Paper					71.5	270.4
28-Chemicals					105.9	478.0
29-Petroleum					118.9	570.2

	1954	1970	1980	2010	1954-1970	1954-1980	1954-2010
Waste Production Per Worker (p.e.)							
20-Food	44	52	60	95	18%	36%	116%
26-Paper	123	200	276	525	63	124	327
28-Chemical	29	44	59	167	52	103	475
29-Petroleum	19	30	37	111	58	95	484

Note: It is extremely important to be clear about the definition employed here. "Waste produced" is taken to mean that amount of oxygen-demanding waste which would be discharged if no treatment occurred. Actual waste discharged is in many (possibly most) cases substantially less than waste produced.

Clearly the concept of "treatment" is ambiguous; some industrial processes increase wastes, some reduce them (especially many by-product recovery processes). The projections of waste production therefore may be too high because new processes within plants could reduce waste content of discharges; they are certainly much higher than the wastes actually to be discharged from industries. Rudolfs (op. cit.) does not clearly indicate whether his waste figures, on which the current levels of waste per employee are based, are measured before any in-plant treatment takes place.

ratio of the projected rate of increase of total waste to the projected rate of increase of total waste to the projected rate of increase of output.[8] This yields an estimate of waste per employee adjusted for expected changes in waste per unit output.

The result obtained above is next multiplied by the projected rate of increase of output per employee[9] to adjust waste per employee for productivity changes. The final results are shown in the bottom rows of Table 6, along with implied rates of change of waste per worker. Figures for 1970 are derived by interpolation between 1954 and 1980.

Each of the projected employments in each industry by region were multiplied by the appropriate factor of waste production per employee and the results summed to give total industrial waste production in Tables 1 to 5; this sum was then added to municipal waste production to yield projections of all BOD wastes produced (in population equivalents) for each region.

At this point, a major element of public policy enters into the analysis. The right of government to regulate the amount of wastes entering streams is well-established. It is possible to treat oxygen-demanding wastes before discharge so as to remove at least 90 to 95 percent of the BOD originally present, and it will be shown that the occurrence of water shortages in 1970, 1980 and 2010 depends very substantially upon the overall degrees of waste treatment which are expected to take place. For the most part in this report, we show the consequences of two treatment levels, designated "low" and "high." The former assumes waste treatment in 1970 of 75 percent, in 1980 of 80 percent, and in 2010 of 90 percent; the latter assumes in 1970, 80 percent and in both 1980 and 2010, 95 percent. The reasons for choosing these particular levels will be spelled out in Chapter X in some detail. Both levels are considerably higher than the estimated present overall treatment level of some 45 to 50 percent.

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[8] Percentage increase in total waste discharge by industry, 1980 and 2000 from Table VI-3, page VI-8c of the Wollman manuscript. Percentage increase in output by industry 1980 and 2000, Table IV-12, page 30a, Wollman manuscript.

[9] Percentage increases in output per employee from data presented by John Kendrick for period 1893 to 1953 (in Productivity Trends in the United States, National Bureau of Economic Research, Princeton University Press, Princeton 1961.)

In addition to projecting the amount of BOD wastes which will be discharged in each region, it is further necessary to make some assumptions about the proportions of such wastes which are likely to be discharged to specific stream systems or water bodies. It is particularly important to project the portions discharged to salt or brackish waters. The paucity of data on the proportions of existing BOD discharges which are to brackish water makes projection especially uncertain; incorporating a scanty knowledge of the current situation with reasonable assumptions as to future developments, we assume the discharge dispositions shown in Table 7. When these proportions are applied to the waste discharges given in Tables 1 - 5, the results are the projected waste loads to be assimilated by receiving waters in each region; these are recorded in Tables 8 through 10. Note our expectation that all wastes in Regions I and V will be discharged to salt or brackish water.[9a] The problems this raises for estuarial water quality are discussed later in this chapter.

[9a] Note also that possible reuse of waste water before such discharge would be equivalent to decreasing consumptive use.

TABLE 7

Proportions of Wastes Assumed to be Discharged to Salt or Brackish Water - Maryland Regions

	Region I Bay and Potomac Estuary	Region II	Region III Bay	Region IV Potomac Estuary	Region V Bay and Atlantic Ocean
Municipal	100%	None	100%	95%	100%
Industries					
20-Food processing	100%	None	95%	90%	100%
26-Pulp and paper	100%	None	95%	95%	100%
28-Chemicals	100%	None	95%	95%	100%
29-Petroleum and coal products	100%	None	100%	100%	100%
33-Primary metals	100%	None	100%	100%	100%

TABLE 8

Disposition of Wastes Discharged
Region II, Western Maryland
Alternative Treatment Levels
(units p.e. unless otherwise shown)

	1970		1980		2010	
	Low (75%)	High (80%)	Low (80%)	High (95%)	Low (90%)	High (95%)
North of Potomac-						
Municipal wastes discharged	103,175	82,540	91,240	22,810	64,080	32,040
Maryland industrial waste discharged						
20-Food processing	28,600	22,880	27,600	6,900	29,450	14,725
26-Pulp and paper	110,000	88,000	132,480	33,120	194,250	97,125
28-Chemicals	5,500	4,400	9,440	2,360	15,030	7,515
33-Primary metals	250	200	200	50	200	100
Pennsylvania industrial waste discharged	35,300	28,240	31,740	7,935	22,300	11,150
Percents discharged to Potomac						
Maryland municipal	20%	20%	20%	20%	20%	20%
Maryland industrial						
20-Food processing	25%	25%	25%	25%	25%	25%
26-Pulp and paper	100%	100%	100%	100%	100%	100%
28-Chemicals	90%	90%	90%	90%	90%	90%
33-Primary metals	50%	50%	50%	50%	50%	50%
Pennsylvania municipal and industrial	0%	0%	0%	0%	0%	0%
Amounts to Potomac-						
Municipal	20,635	16,508	18,248	4,562	12,816	6,408
Maryland industrial total	122,225	97,780	147,976	36,994	215,240	107,619
Total to Potomac from North	142,860	114,288	166,224	41,556	228,056	114,027
Amounts to streams north of Potomac						
Municipal	82,540	66,032	72,992	18,248	51,264	25,632
Maryland industrial	22,125	17,700	21,744	5,436	23,690	11,846
Pennsylvania industrial	35,300	28,240	31,740	7,935	22,300	11,150
Total north of Potomac	139,965	111,972	126,476	31,619	97,254	48,628
South of Potomac-						
Municipal wastes discharged	93,025	74,420	83,940	20,985	60,542	30,271
Industrial waste discharged	93,025	74,420	83,940	20,985	60,542	30,271
Percents discharged to Potomac						
Municipal	25%	25%	25%	25%	25%	25%
Industrial	45%	45%	45%	45%	45%	45%
Amounts discharged to Potomac						
Municipal	23,256	18,605	20,985	5,246	15,136	7,568
Industrial	41,861	33,489	37,773	9,443	27,244	13,623
Amounts discharged to streams south of Potomac						
Municipal	69,769	55,815	62,955	15,739	45,406	22,703
Industrial	51,164	40,931	46,167	11,542	33,298	16,649
Total	120,933	96,746	109,122	27,280	78,705	39,352
Total to Potomac from South	65,117	52,094	58,758	14,690	42,380	21,190
Potomac Mainstem-						
Total to Potomac from North and South	207,977	166,382	224,982	56,246	270,436	128,809

TABLE 9

Disposition of Wastes Discharged
Region III, Baltimore Metropolitan Area
Alternative Treatment Levels
(units p.e. unless otherwise shown)

	1970		1980		2010	
	Low	High	Low	High	Low	High
Municipal wastes discharged	528,250	422,600	508,400	127,100	398,900	199,450
Industrial wastes discharged						
20-Food processing	302,900	242,320	291,600	72,900	237,500	118,750
26-Pulp and paper	170,000	136,000	226,800	56,700	307,500	153,750
28-Chemicals	193,600	154,880	218,300	54,575	362,390	181,195
29-Petroleum and coal	7,500	6,000	8,880	2,220	17,760	8,880
33-Primary metals	49,750	39,800	42,800	10,700	43,900	21,950
Percents discharged to Chesapeake Bay after treatment						
Municipal	100%	100%	100%	100%	100%	100%
Industrial						
20-Food processing	95%	95%	95%	95%	95%	95%
26-Pulp and paper	100%	100%	100%	100%	100%	100%
28-Chemicals	95%	95%	95%	95%	95%	95%
29-Petroleum and coal	100%	100%	100%	100%	100%	100%
33-Primary metals	100%	100%	100%	100%	100%	100%
Amounts to Bay						
Municipal	528,250	422,600	508,400	127,100	398,900	199,450
Total industrial	698,925	559,140	762,885	190,721	939,055	469,527
Total	1,227,175	981,740	1,271,285	317,821	1,337,955	668,977
Amounts to streams						
Municipal	--	--	--	--	--	--
Total industrial	24,825	19,860	25,495	6,374	29,995	14,998
Total	24,825	19,860	25,495	6,374	29,995	14,998

TABLE 10

Disposition of Wastes Discharged
Region IV, Washington Metropolitan Area
Alternative Treatment Levels
(units p.e. unless otherwise shown)

	1970		1980		2010	
	Low	High	Low	High	Low	High
Maryland municipal wastes discharged	255,750	204,600	264,200	66,050	230,500	115,250
Maryland industrial wastes discharged						
20-Food processing	35,100	28,080	36,000	9,000	30,400	15,200
26-Pulp and paper	10,000	8,000	14,000	3,500	22,500	11,250
28-Chemicals	36,300	29,040	41,300	10,325	58,450	29,225
29-Petroleum and coal	2,250	1,800	2,220	555	5,550	2,775
33-Primary metals	125	100	100	25	100	50
District of Columbia wastes discharged	192,120	153,696	157,992	39,498	89,500	44,750
Virginia wastes discharged	176,825	141,460	179,220	44,805	161,100	80,550
Percents discharged to Potomac Estuary						
Maryland municipal	95%	95%	95%	95%	95%	95%
Maryland industrial						
20-Food processing	90%	90%	90%	90%	90%	90%
26-Pulp and paper	95%	95%	95%	95%	95%	95%
28-Chemicals	95%	95%	95%	95%	95%	95%
29-Petroleum and coal	100%	100%	100%	100%	100%	100%
33-Primary metals	100%	100%	100%	100%	100%	100%
District of Columbia	100%	100%	100%	100%	100%	100%
Virginia SMSA part	100%	100%	100%	100%	100%	100%
Amounts to Potomac Estuary						
Maryland municipal	242,962	194,370	250,990	62,748	218,975	109,488
Maryland industrial	77,950	62,360	97,255	21,814	109,913	54,957
District of Columbia	192,120	153,696	157,992	39,498	89,500	44,750
Virginia SMSA part	176,825	141,460	179,220	44,805	161,100	80,550
Total	689,857	551,886	685,457	168,865	579,488	289,745
Amounts to streams in region						
Municipal	12,788	10,230	13,210	3,302	11,525	5,762
Industrial	5,825	4,660	6,365	1,591	7,087	3,543
Total	18,613	14,890	19,575	4,893	18,612	9,305

C. Streamflow requirements for waste assimilation

The problem to be discussed here is one whose answers come ultimately from the fields of aquatic biology, sanitary engineering, fluid mechanics, and chemistry. Since some quantitative estimates of streamflows required to maintain water quality are essential to the conclusions of the study, an attempt has been made to use the current state of applied science in these fields, but it has become clear that the results are based in many cases on rather simple approximations to very complex conditions, and must be regarded as subject to considerable error.

The action of stream waters on oxygen-demanding wastes is not simply one of dilution - although dilution itself is important, since standards are expressed in terms of parts of BOD per million parts of water. Beyond dilution, however, a biological process takes place as minute bacterial organisms consume organic wastes and simultaneously use up dissolved oxygen present in most waters.[10] The two processes of waste consumption and oxygen depletion proceed at different rates over time, since the latter is slowed down and eventually reversed in all but the most severely polluted waters by reaeration - the replacement of dissolved oxygen from the atmosphere, or from the process of photosynthesis in some aquatic plants.

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[10] A Study of the Pollution and Natural Purification of the Ohio River, H. W. Streeter and E. B. Phelps. U. S. Public Health Service, Public Health Bulletin #146. U. S. Government Printing Office, 1925. Estimates given in this report indicate that three-fourths of the purification occurring in the Ohio River was attributable to the biological reaction.

The typical profile of a single waste discharge into a running stream is therefore as shown in Figure 1: the level of BOD declines, at first rapidly, then more gradually, while the level of dissolved oxygen (DO) dips rapidly, then recovers at a decreasing rate (this DO profile is known as the "oxygen sag" curve).[11]

Disposal of waste to streams is, therefore, actually a form of treatment, and in controlled quantities and at controlled times may be a perfectly legitimate substitute for treatment before discharge. Note, however, that excessively high BOD levels may occur close to the waste outfall (say point A in Figure 1), or excessively low DO values at the low point (or "critical point," B in Figure 1) of the oxygen sag curve. These are the limiting factors, therefore, in the use of streams to assimilate wastes.

Several paths have been followed in determining the streamflows required to assimilate the projected volumes of wastes without violating quality standards. (All but one of these paths have concentrated on the DO level, and so may allow transient violations of BOD standards.)

1. Oxygen Sag Calculations

The oxygen sag relationship has been extensively investigated and given precise mathematical formulation. This formulation makes it possible to solve for the streamflow required in a given reach of a stream to assimilate a specified waste load without letting the level of DO

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[11] See Water Supply and Waste-Water Disposal, G. M. Fair and J. Geyer. J. Wiley and Sons, New York, 1954. Also Streeter and Phelps.

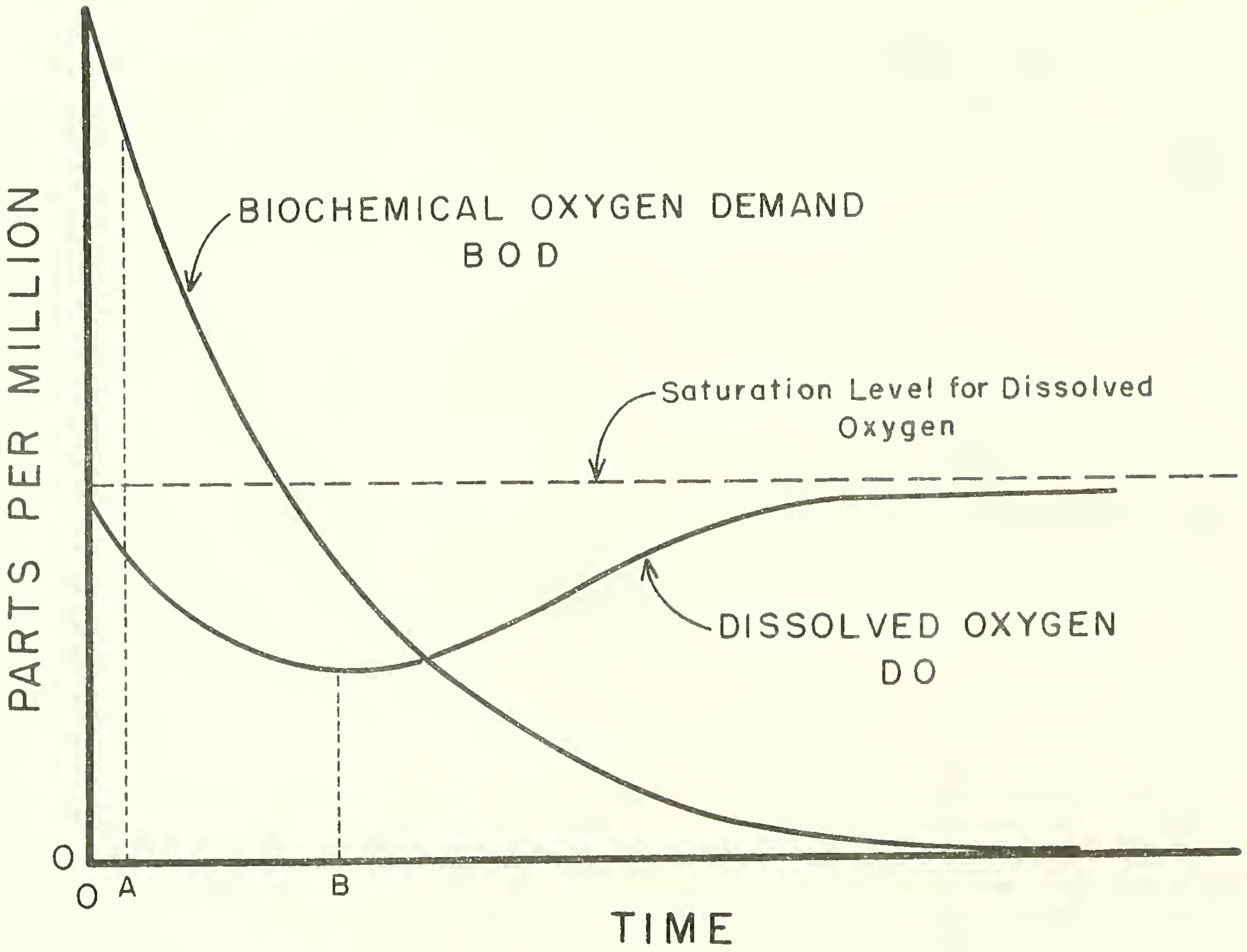

Figure 1

Illustrative Oxygen Sag and B O D Assimilation Curves fall below a specified standard.[12] The equation contains two parameters (k_1 and k_2) which represent, respectively, the rate at which BOD is consumed (and therefore, also the rate at which oxygen is depleted), and the rate at which oxygen is reacquired from the environment. Both of these elements depend upon temperature, and the second also depends on many physical characteristics of the stream which determine its turbulence and amount of air contact.

The equation was solved by treating the entire flow in all streams of a region as flow at a single point,[13] and all wastes as discharge at a single point, and using several alternative values of k_1 and k_2 (corresponding roughly to alternative stream characteristics). The results are shown in Table 11, expressed in terms of the number of population equivalents of BOD wastes which can be assimilated by one million gallons of streamflow per day. Clearly, this approach gives only an approximation, since the actual pattern of flows in individual streams and the locations of waste discharges to those streams does affect the total assimilation capacity of a stream system.

2. Public Health Service Potomac Study Results

A second source of estimates of stream waste assimilation capacities is the report prepared by the United States Public Health

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[12] The Streeter-Phelps equation was transposed to solve directly for the assimilation capacity, A in population equivalents per m.g.d. as a function of the quality standard (expressed as a critical deficit below saturation oxygen level in parts per million, Dc) and the ratio of the two physical parameters $f = k_2 | k_1$; $A = 33.33\, D_c f^{\left[\frac{f}{f-1}\right]}$. There are many complicating factors in stream regime not taken into account by the Streeter-Phelps equation, however.

[13] This quantity is calculated in Chapter IX.

TABLE 11

Waste Assimilation Capacity of Streams - Calculations from Oxygen Sag Curve (Dissolved Oxygen Standard, 5 p.p.m.)

Value of f (= k_2/k_1)	Stream Conditions Corresponding to f level	Assimilation Capacity p.e./m.g.d.
0.5	Small ponds, back waters	278
1.0	Sluggish streams, lakes	376
1.5	Large streams, low velocity	479
2.0	Large streams, normal velocity	558
3.0	Swift streams	727
5.0	Waterfalls, rapids	1,048

Source: Calculations from equation in Footnote 12. Table of f values and characteristics, Kerr Committee Print #29, p. 5.

Service in cooperation with the Army Corps of Engineers and published as Volume V of the Potomac River Basin Report.[14] At a number of points in this report, waste assimilation capacities are reported for specific reaches of particular streams in the Potomac Basin. These capacities, calculated from field data, are given in population equivalents per cubic foot per second of streamflow, and require two adjustments before they become comparable to those given in Table 11. First, since the Public Health Service uses a population equivalent unit equal to 0.17 lbs. of BOD, while we employ one of 0.24 lbs., each Public Health Service figure must be multiplied by the ratio 0.17/0.24 (=0.708); second, to express capacities per million gallons per day of flow (instead of cubic feet per second) the result must be divided by 0.646. The range of Public Health Service assimilation capacities for Potomac Basin streams is given in Table 12. It can be seen that these are substantially lower than those previously computed by the oxygen sag formula.[14a]

TABLE 12

Waste Assimilation Capacity of Streams -

Public Health Service Potomac Study
(DO standard 5 p.p.m.)

	p.e. (0.17 lbs. BOD) per cfs	p.e. (0.24 lbs. BOD) per m.g.d.
Low Value	92	101
Median Value	200	217
High Value	240	263

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[14] The wealth of specific data for Maryland streams in this report is a valuable supplement to our more generalized approach in this study.

[14a] This difference is partly explained by the P.H.S. use of critical stream conditions, including temperatures higher than the 20° C we have employed.

3. A Computer Model of Streamflow and Waste Assimilation

To tackle the difficult problem of stream assimilation in many of its complexities, we have also worked during the study on the construction of a computer model into which can be programmed basic data representing any particular stream system, and from which can be calculated stream quality (both DO and BOD) at any desired points. This model, which also calculates minimum cost combinations of waste treatment and increased streamflow for a stream system, is described more fully in Appendix B. Because of data requirements, only a small sample problem has been solved at the time of writing.

Some tentative results from this model based on data for the Monocacy River system suggest that even the assimilation capacities presented in Table 11 may be too low under complex stream conditions.[15]

4. Range of Assimilation Capacities Employed

From the several approaches outlined here, aided by comments from the Technical Advisory Committee to this study, three assimilation capacities have been chosen to represent low, medium, and high estimates. The low capacity is 217 p.e. per m.g.d., approximately the median of the Public Health Service Potomac estimates. The high capacity is 650 p.e. per m.g.d., which results from our oxygen sag equations for stream conditions roughly typical of large streams of high velocity. The medium capacity is a compromise of 400 p.e. per m.g.d.[16] The rather large range between low and high capacities (a range which might well be made even larger) reflects in this case a great deal of uncertainty about the physical relations underlying waste assimilation in streams and about the best way to generalize these relations over a region. This is pointed out again in the final chapter as one area requiring better data and research techniques.

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[15] We have also attempted calculations using the formula developed by George Reid in Kerr Committee Print #29. This formula was devised to calculate streamflow requirements for quality maintenance for major river basins of the United States and, like our first approach, gives extremely generalized results. However, these estimates are highly sensitive to elements of the Reid formula which are acknowledged by Reid to involve "considerable judgement" and which are difficult to interpret; we therefore do not use them for Maryland regions. In general, this approach apparently gives much lower assimilation capacities than the other sources.

One can note also from Tables 8 to 10 that we expect a major part of wastes in Maryland to be discharged to salt or brackish waters, primarily those of the Chesapeake Bay or its many tidal estuaries. The assimilation of wastes in such waters is a biologically and mechanically complex process which is now the subject of several major studies. We do not deal directly with the problem here, partly because it apparently cannot be solved simply by increasing streamflows beyond our projections, partly because it is not within the scope of our contract; however, it must be viewed as a very important issue for the State. The estuarial and Chesapeake Bay waters of Maryland are a resource of immense present and potential importance which should not be lost through pollution. Our estimates of waste discharges to such waters may be of some value to later studies.

D. Streamflows required for quality maintenance under alternative assumptions

To sum up, the amount of water required as streamflow to carry, dilute, and destroy oxygen-demanding wastes is dependent on several factors:

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16. Approximately this level has often been used by sanitary engineers as a "rule of thumb" ratio.

1. The amount of waste generated by the population and economic activities of a region.
2. The degree of treatment of such waste before its discharge to water bodies.
3. The proportion of discharged wastes which go to the fresh-water streams of a region.
4. The assimilation capacity of the fresh-water streams of a region.
5. The standard which is set for stream quality in a region (in terms here of dissolved oxygen levels).

We cannot predict with certainty what any of the five factors will be for 1970, 1980, or 2010; we have only approximate knowledge of most of them for 1964. It is useful, however, to look at groups of the factors in different ways. The degree of waste treatment, the stream quality standard, and, to a lesser extent, the selection of water bodies to which treated wastes are to be discharged, are subject to deliberate public policy and control. We try here to keep the first two in sight as policy alternatives throughout the final chapters. The assimilation capacity of streams is a physical fact which is viewed as a variable only because of our limited knowledge; similarly, future population and industrial activity underlying projections of waste production are treated at alternative levels primarily because of uncertainty (although public policies could affect both population and industrial locations among and within regions to some extent).

Therefore, the quality maintenance element of water demand is calculated in Tables 13 to 15 under a number of alternative levels of both policy choices and aspects about which uncertainty exists.

The specific choice of the two water quality standards used in our calculations, 5 p.p.m. and 4 p.p.m. of dissolved oxygen, is based on broad criteria established by the Interstate Commission on the Potomac River Basin. Water with a 5 p.p.m. minimum dissolved oxygen level is identified by the Commission as suitable for bathing, fish life, domestic water supply (before treatment), and industrial process water (providing that other dimensions of quality are also met). The lower requirement of 4 p.p.m. dissolved oxygen implies somewhat higher quality levels than those necessary to prevent nuisance and health hazard, but may not be suitable for the purposes listed above. While these standards are rough indicators of overall water quality, they are widely accepted and are adequate to make the point that substitution is possible in the selection of standards.

TABLE 13

Quality Maintenance Flow Requirements, by Sections
Region II, Western Maryland
(mgd)

		North of Potomac Pop. Projections		South of Potomac Pop. Projections		Potomac Main stem Pop. Projections		Ohio Basin Portion Pop. Projections	
		Med.	High	Med.	High	Med.	High	Med.	High
						1970			
	75% Treatment								
5 ppm	Low Assimilation	645	677	557	585	1005	1055	12	13
	Med Assimilation	350	368	302	317	545	572	6	7
	High Assimilation	215	226	186	195	335	352	4	4
4 ppm	Low Assimilation	479	503	414	435	746	783	9	9
	Med Assimilation	262	275	226	237	407	427	5	5
	High Assimilation	161	169	139	146	251	264	3	3
	80% Treatment								
5 ppm	Low Assimilation	516	542	446	468	767	805	10	10
	Med Assimilation	280	294	242	254	416	437	5	5
	High Assimilation	172	181	149	156	256	269	3	3
4 ppm	Low Assimilation	383	402	331	348	570	598	7	7
	Med Assimilation	209	219	181	190	311	327	4	4
	High Assimilation	129	135	111	117	191	201	2	3
						1980			
	80% Treatment								
5 ppm	Low Assimilation	583	647	503	558	1037	1151	11	12
	Med Assimilation	316	351	273	303	562	624	6	7
	High Assimilation	195	216	168	186	346	384	4	4
4 ppm	Low Assimilation	433	481	374	415	770	855	8	9
	Med Assimilation	236	262	204	226	421	467	4	5
	High Assimilation	145	161	125	139	259	287	3	3
	95% Treatment								
5 ppm	Low Assimilation	146	162	126	140	259	287	3	3
	Med Assimilation	79	88	68	75	141	157	2	2
	High Assimilation	49	54	42	47	87	97	1	1
4 ppm	Low Assimilation	108	120	96	107	193	214	2	2
	Med Assimilation	59	65	51	57	105	117	1	1
	High Assimilation	36	40	31	34	65	72	1	1
						2010			
	90% Treatment								
5 ppm	Low Assimilation	448	605	363	490	1246	1682	7	9
	Med Assimilation	243	328	197	266	676	913	4	5
	High Assimilation	150	202	121	163	416	562	2	3
4 ppm	Low Assimilation	333	450	270	364	926	1250	5	7
	Med Assimilation	182	246	147	198	505	682	3	4
	High Assimilation	112	151	90	122	311	420	2	2
	95% Treatment								
5 ppm	Low Assimilation	224	302	181	244	623	841	3	5
	Med Assimilation	122	165	98	132	338	456	2	3
	High Assimilation	75	101	61	82	208	281	1	2
4 ppm	Low Assimilation	166	224	135	182	463	625	3	3
	Med Assimilation	91	123	74	100	253	342	1	2
	High Assimilation	56	76	45	61	155	209	1	1

TABLE 14

Quality Maintenance Flow Requirements
Region III, Baltimore Metropolitan

		To Streams	
		Med.	High
	1970		
	75% Treatment		
5 ppm	Low Assimilation	114	120
	Med Assimilation	62	65
	High Assimilation	38	40
4 ppm	Low Assimilation	85	89
	Med Assimilation	46	48
	High Assimilation	29	30
	80% Treatment		
5 ppm	Low Assimilation	92	97
	Med Assimilation	50	52
	High Assimilation	31	33
4 ppm	Low Assimilation	68	71
	Med Assimilation	37	39
	High Assimilation	23	24
	1980		
	80% Treatment		
5 ppm	Low Assimilation	117	130
	Med Assimilation	64	71
	High Assimilation	39	43
4 ppm	Low Assimilation	87	97
	Med Assimilation	48	53
	High Assimilation	29	32
	95% Treatment		
5 ppm	Low Assimilation	29	32
	Med Assimilation	16	18
	High Assimilation	10	11
4 ppm	Low Assimilation	22	24
	Med Assimilation	12	13
	High Assimilation	7	8
	2010		
	90% Treatment		
5 ppm	Low Assimilation	138	186
	Med Assimilation	75	101
	High Assimilation	46	62
4 ppm	Low Assimilation	103	139
	Med Assimilation	56	76
	High Assimilation	34	46
	95% Treatment		
5 ppm	Low Assimilation	69	93
	Med Assimilation	37	50
	High Assimilation	23	31
4 ppm	Low Assimilation	51	69
	Med Assimilation	28	38
	High Assimilation	17	23

TABLE 15

Quality Maintenance Flow Requirements
Region IV, Washington Metropolitan
(mgd)

		In Region IV Streams	
		Population Projections	
		Med.	High
	1970		
	75% Treatment		
5 ppm	Low Assimilation	86	90
	Med Assimilation	47	49
	High Assimilation	29	30
4 ppm	Low Assimilation	64	67
	Med Assimilation	35	37
	High Assimilation	21	22
	80% Treatment		
5 ppm	Low Assimilation	69	72
	Med Assimilation	37	39
	High Assimilation	23	24
4 ppm	Low Assimilation	51	54
	Med Assimilation	28	29
	High Assimilation	17	18
	1980		
	80% Treatment		
5 ppm	Low Assimilation	90	100
	Med Assimilation	49	54
	High Assimilation	30	33
4 ppm	Low Assimilation	67	74
	Med Assimilation	37	41
	High Assimilation	22	24
	95% Treatment		
5 ppm	Low Assimilation	23	26
	Med Assimilation	12	13
	High Assimilation	7	8
4 ppm	Low Assimilation	17	19
	Med Assimilation	9	10
	High Assimilation	6	7
	2010		
	90% Treatment		
5 ppm	Low Assimilation	86	116
	Med Assimilation	47	63
	High Assimilation	29	39
4 ppm	Low Assimilation	64	86
	Med Assimilation	35	47
	High Assimilation	21	28
	95% Treatment		
5 ppm	Low Assimilation	43	58
	Med Assimilation	23	31
	High Assimilation	14	19
4 ppm	Low Assimilation	32	43
	Med Assimilation	17	23
	High Assimilation	11	15

CHAPTER VIII

SUMMARY OF FRESH WATER WITHDRAWAL DEMANDS

A. Introduction

The analysis and projections of demands for fresh water in Maryland are now complete. Chapters III-VI have been concerned with withdrawals and consumptions of water for household, commercial, municipal, institutional, industrial, agricultural and recreational purposes. Chapter VII has been concerned with instream requirements of fresh water for waste assimilation. The next task is to add together the various demands and to compare them with available and potential supplies. This chapter presents the first steps in the accomplishment of this task.

As indicated in Chapter I, the economically relevant measure of withdrawal demand for water is the excess of withdrawals over returns, i.e., the amount of water consumed in use. It should also be recalled that the concept of consumption employed in the estimates and projections of previous chapters has been a broad one. It includes not only the incorporation of water into industrial products, evaporation and transpiration, but also discharges into salt and brackish bodies.

The relevant concept of total demand must include not only these consumptive uses but also the instream requirements for waste assimilation that were presented in Chapter VII. In other words, total required streamflow is the amount withdrawn from the stream but not replaced, plus the amount that must be left in the stream for waste assimilation after consumptive uses have been met.

It seems best to proceed by adding these demands together in two steps.

In this chapter, the first step will be taken by adding together the projections of fresh water consumption from Chapters III-VI. To facilitate reference, all the consumptive uses will be presented in one place. Then, in Chapter X, the second step will be taken by adding the quality maintenance flows to the consumptive uses.

High, medium and low projections of all consumptive uses have been presented in previous chapters. Furthermore, the projections in Chapter VII of flows needed for waste assimilation were made on the basis of two stream quality levels, two sets of assumed treatment levels, and three assumed average stream assimilation capacities. There are 36 combinations of these assumptions, and they make possible 36 projections of total water demand for each of the five Regions of the State and each of the three projection dates. It is clear that the detailed calculations in the following chapters will have to be restricted to a small number of combinations. Indeed, this procedure of selection has already been started in the previous chapter, where the calculations of flows needed for waste assimilation were made for only the high and medium population projections. In cases where the alternatives represent public and private choices, as with treatment levels and stream quality levels, selection can be made on the basis of plausibility and evidence from other studies as to which combinations are more nearly optimum than others. In cases where the alternatives represent ignorance about the future or about technical matters, as with population projections and stream assimilation capacities, selection must be made on the basis of plausibility alone.

A major reason for carrying out as much of the analysis as possible for all possible combinations of assumptions is to make it possible for the user of this report to repeat the calculations with his own assumptions. For that reason, all the high, medium and low projections of consumption are presented in the next Section, even though not all of them are used in the subsequent calculations.

B. Total consumptive demands

Table 1 presents estimated fresh-water consumption in Maryland for 1960. Tables 2, 3, and 4 present projections of fresh-water consumption in Maryland for 1970, 1980 and 2010. The data in these tables are all totals from tables on water consumption in Chapters III to VI.

TABLE 1

Estimated Water Consumption in Maryland, 1960

(000 Gallons Per Day)

Region	Industry	Agriculture	Household, Commercial, Municipal	Recreation	Thermal Electric	Total
I - Southern Md.	841	308	5,328	75	-	6,552
II - Western Md.	3,668	4,067	6,793	180	1,595	16,303
III - Baltimore Metro.	240,274	-	145,662	-	-	385,936
IV - Washington Metro.	6,058	-	112,831	-	4,737	123,626
V - Eastern Shore	16,477	14,674	33,954	300	-	65,405
Maryland	267,318	19,049	304,568	555	6,332	597,822

TABLE 2

Projected Water Consumption in Maryland, 1970

(000 Gallons Per Day)

Region	Industry	Agriculture	Household, Commercial, Municipal	Recreation	Thermal Electric	Total
High						
I - Southern Md.	4,401	2,088	9,089	114	-	15,692
II - Western Md.	4,325	9,883	9,048	215	1,734	25,205
III - Baltimore Metro.	322,531	-	192,427	-	-	514,958
IV - Washington Metro.	27,476	-	180,818	-	5,776	214,070
V - Eastern Shore	28,633	48,424	41,946	354	-	119,357
Maryland	387,366	60,395	433,328	683	7,510	889,282
Medium						
I - Southern Md.	4,401	1,934	8,619	108	-	15,062
II - Western Md.	4,149	8,541	8,627	205	1,652	23,174
III - Baltimore Metro.	308,698	-	176,886	-	-	485,584
IV - Washington Metro.	26,232	-	172,538	-	5,507	204,277
V - Eastern Shore	27,581	37,859	40,170	339	-	105,949
Maryland	371,061	48,334	406,840	652	7,159	834,046
Low						
I - Southern Md.	4,401	502	8,306	104	-	13,313
II - Western Md.	4,004	5,572	8,317	198	1,594	19,685
III - Baltimore Metro.	297,406	-	166,413	-	-	463,819
IV - Washington Metro.	25,342	-	166,661	-	5,324	197,327
V - Eastern Shore	26,423	27,147	38,681	326	-	92,577
Maryland	357,576	33,221	388,378	628	6,918	786,721

TABLE 3

Projected Water Consumption in Maryland, 1980

(000 Gallons Per Day)

Region	Industry	Agriculture	Household, Commercial, Municipal	Recreation	Thermal Electric	Total
			High			
I - Southern Md.	6,274	16,293	14,887	181	-	37,635
II - Western Md.	5,331	24,440	10,939	300	1,945	42,955
III - Baltimore Metro.	423,926	-	301,353	-	-	725,279
IV - Washington Metro.	41,884	-	258,520	-	6,203	306,607
V - Eastern Shore	38,300	162,927	59,654	524	-	261,405
Maryland	515,715	203,660	645,353	1,005	8,148	1,373,881
			Medium			
I - Southern Md.	5,899	13,849	14,417	162	-	34,327
II - Western Md.	4,869	17,922	10,623	270	1,748	35,432
III - Baltimore Metro.	382,386	-	287,380	-	-	669,766
IV - Washington Metro.	37,631	-	250,319	-	5,562	293,512
V - Eastern Shore	34,573	89,610	53,490	470	-	178,143
Maryland	465,358	121,381	616,229	902	7,310	1,211,180
			Low			
I - Southern Md.	5,523	815	13,268	149	-	19,755
II - Western Md.	4,543	7,331	9,761	248	1,607	23,490
III - Baltimore Metro.	349,682	-	251,415	-	-	601,097
IV - Washington Metro.	34,084	-	229,790	-	5,112	268,986
V - Eastern Shore	31,523	48,879	49,207	432	-	130,041
Maryland	425,355	57,025	553,441	829	6,719	1,043,369

TABLE 4

Projected Water Consumption in Maryland, 2010

(000 Gallons Per Day)

Region	Industry	Agriculture	Household, Commercial, Municipal	Recreation	Thermal Electric	Total
			High			
I - Southern Md.	16,339	32,585	75,769	565	-	125,318
II - Western Md.	10,000	40,732	38,320	714	3,806	93,572
III - Baltimore Metro.	716,487	-	1,205,911	-	-	1,922,398
IV - Washington Metro.	68,287	-	817,506	-	9,388	895,181
V - Eastern Shore	71,181	325,854	210,096	1,313	-	608,444
Maryland	882,294	399,171	2,347,602	2,592	13,194	3,644,853
			Medium			
I - Southern Md.	12,220	14,664	55,789	416	-	83,089
II - Western Md.	7,415	19,552	28,174	525	2,301	57,967
III - Baltimore Metro.	529,870	-	838,269	-	-	1,368,139
IV - Washington Metro.	49,500	-	601,559	-	6,904	657,963
V - Eastern Shore	54,123	162,927	117,115	967	-	335,132
Maryland	653,128	197,143	1,640,906	1,908	9,205	2,502,290
			Low			
I - Southern Md.	9,520	1,629	42,338	315	-	53,802
II - Western Md.	5,589	13,034	21,413	399	2,128	42,563
III - Baltimore Metro.	399,286	-	586,305	-	-	985,591
IV - Washington Metro.	35,368	-	454,773	-	5,224	495,365
V - Eastern Shore	39,502	89,610	88,541	731	-	218,384
Maryland	489,265	104,273	1,193,370	1,445	7,352	1,795,705

CHAPTER IX

WATER SUPPLY IN MARYLAND REGIONS

A. Introduction

Certain conceptual and practical difficulties are encountered in measuring the supply of water in Maryland. These problems arise, in part, from divergent definitions of the noun "supply." In common usage, "supply" may be considered "the quantity (of a commodity) at hand." But economists have defined "supply" as "the schedule of quantities of any article offered at alternative prices." This Chapter will note the difficulties inherent in these definitions as they apply to this discussion, and will, moreover, explore the problems posed by the protean nature of the resource itself.

The first of these difficulties is the derivation of a quantity measure of a resource which is continually in motion and in change of state. The physical amount of water in any particular region in any particular point of time is partly in the form of vapor in the atmosphere, partly in the form of water flowing on the surface of the earth, or resting in impoundments on the surface, and partly in the form of water percolating through the ground or underground aquifers or stationary in some cases in underground reservoirs. Water is continually moving from one of these states or conditions into another.

The theory and practice of measurement of water quantity are far more advanced for some portions of the hydrologic cycle than for others. In general, measurements of surface water are much more available than of underground or atmospheric or subsurface water. In addition, the process of withdrawal for use differs substantially for water in different stages of the cycle. Most intentional withdrawals are from surface flows or impoundments; a significant portion are from underground waters; virtually none come directly from atmospheric waters.[1]

The second difficulty, related to the first, is that a given physical unit of water may be "used" more than once by society. We have made a distinction, therefore, between withdrawals and consumption of water, both of which occasion economic values. Recall from Chapter I, that a withdrawal of water may be partly or wholly returned to a point in the hydrologic cycle where it is again available for further use; consumption of water consists of chemically changing the substance or returning it to points of the hydrologic cycle where it is not available for further use immediately, or in the region under consideration (chiefly evaporation to the atmosphere or discharge to salt water bodies.)

A third difficulty in measuring supply arises because the amount of water in portions of the hydrologic cycle from which water can be withdrawn or consumed by society varies greatly over time. Streams fluctuate in varying patterns from periods of less than a day to periods of several years. Society as a user of water, therefore, faces uncertainty, and must deal with probability distributions of availability over time. Extensive investigations of these distributions are quite recent, and our knowledge of their characteristics is far from exhaustive.

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1. Of course, a vitally important part of agricultural water supplies comes as precipitation directly on farm land. This does not constitute "intentional" withdrawal in areas such as Maryland where precipitation control is not attempted.

There are several ways in which the economists' definition of supply as a schedule of quantities produced at alternative prices or costs is applicable to water. One of these ways is the purposeful provision of storage which can raise the low flows at one end of the frequency distribution of flows closer to the long run mean flow. Such storage can be built and operated only at a cost; costs of alternative levels of storage can be charged against raising assured flow to alternative levels. The construction of these relations of costs to increased minimum flows is the fourth problem explored in this paper.

B. Availability of water in the hydrologic cycle

The best measure of physical water supply seems to be an accounting system in which flows are measured in as many stages of the cycle as possible for an identical time period. Such a "water budget" system provides a maximum degree of flexibility and makes it possible to direct attention to alternative methods of changing supply by use regulation and water management.

Consider water supply in the State of Maryland: Water falls as precipitation from the atmosphere - an average of roughly 19 billion gallons per day over the year. Water flows into the State or along its boundaries in the Susquehanna and Potomac Rivers, and in many smaller streams such as the Youghiogheny, Monocacy, and Nanticoke. These streams originate in other states - New York, Virginia, West Virginia, Delaware, and Pennsylvania. Altogether, they carry into the State an average of some 31 billion gallons per day. Water also flows into Maryland beneath its boundaries in quantities which are not known. Some water is at rest in reservoirs, lakes and ponds; the total average of such storage is perhaps 195 billion gallons. An additional amount of water is in underground "storage," but the quantity is not known.[2]

On the "debit" side are the various ways in which water "leaves" Maryland: A large amount is evaporated directly from land and water surfaces or transpired from the foliage of vegetation, both crops and forests. This amount probably exceeds 11 billion gallons per day. The same rivers and streams which carry water into the State also carry large amounts out again, as do other streams arising within the State. The quantity carried out is about 37 billion gallons per day. An additional and unidentified amount flows out beneath State lines in underground aquifers. Finally, a portion, as discussed in other chapters, is "consumed" in non-agricultural uses. Consumption occurs when water is converted to vapor and enters the atmosphere (as in many cooling uses), undergoes chemical change, or is incorporated in products. For many purposes, effluent water which is discharged to the ocean, bay, or tidal estuaries is also consumed, in the sense that it no longer constitutes part of available fresh water supply. Although there are no complete figures on present consumptive use in Maryland, it is probably less than one billion gallons per day (excluding agriculture).

It is now evident that if there existed accurate measurements of all the sources and destinations of water for every region, an accounting

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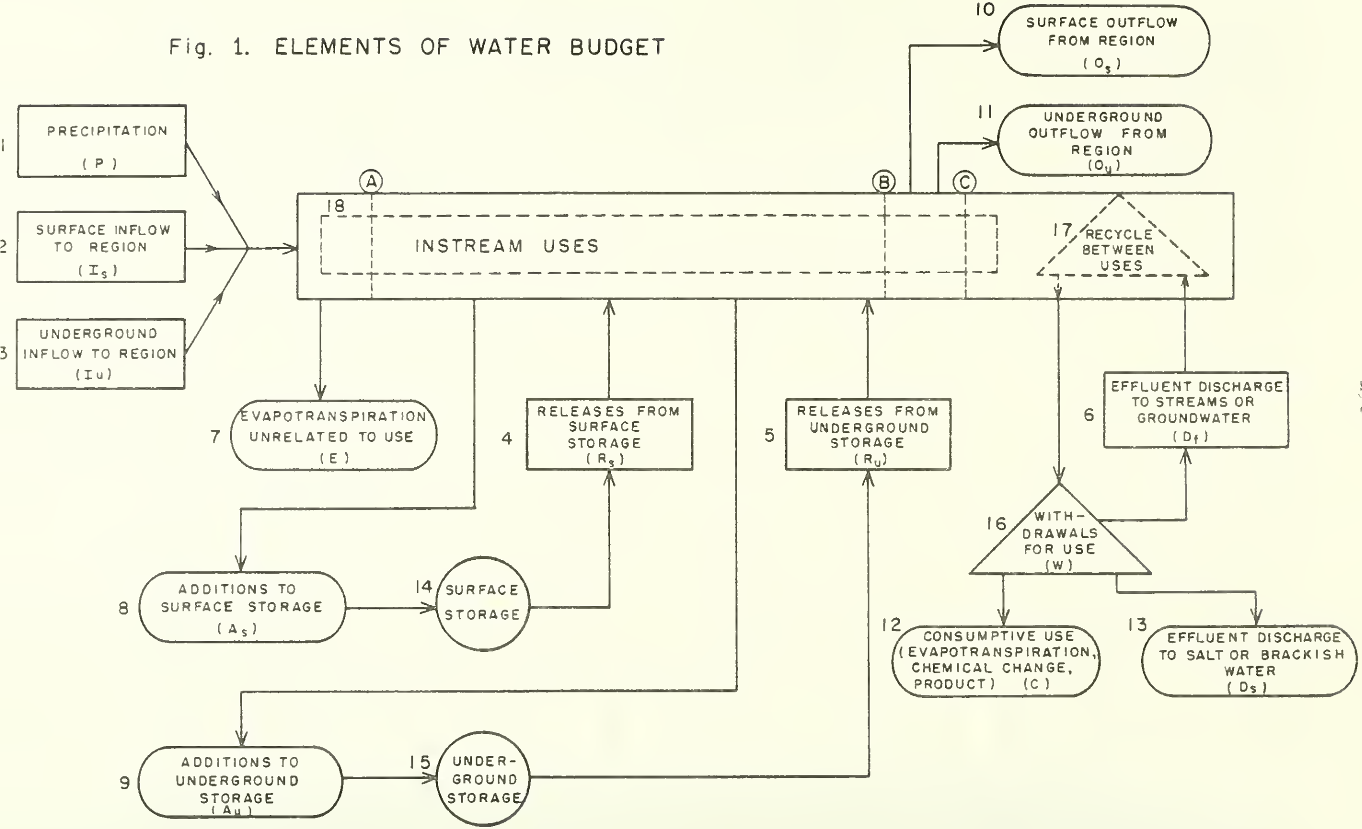
2. Nor would it necessarily be meaningful since it could not all be withdrawn even at astronomical cost. Underground supply will be considered for two Maryland Regions, however.

balance could be drawn up. In its simplest form this balance would state that the total amount of water falling on the State from the atmosphere, or flowing into the State on or beneath the ground must equal the total amount lost to the atmosphere or flowing out of the State via streams or underground plus any net amount added to storage in the State.

Such a formulation, however, is not useful in practice for two reasons: First, not all of the ultimate sources or destinations of water are now measurable; second, this formulation does not identify separately the amount of water potentially available for use by society. Figure 1 is a diagrammatic presentation of the elements of a water balance. Rectangles represent regional sources of water, ovals represent regional dispositions of water, circles represent storage, and triangles represent stages in society's intentional use of water. On the lefthand side, boxes 1, 2, and 3 are the sources which originate water in the region (precipitation from the atmosphere, surface water inflow from outside the region, and underground or groundwater inflow to region). The oval marked 7 represents evapotranspiration prior to (or at any rate unrelated to) man's use of water. Some of this is from the surface of the ground itself or streams or impoundments; some of it is through the growth of plants not grown as economic resources. A measurement of water quantity after these four items have been taken into account is shown at dial A above the long bar in the upper center of the graph. Such a measurement of water flow is essentially a "natural" or "unregulated" flow concept (with the exception that the surface inflow to the region is affected by man's uses outside

Fig. 1. ELEMENTS OF WATER BUDGET


1
PRECIPITATION (P)
2
SURFACE INFLOW TO REGION (I_s)
3
UNDERGROUND INFLOW TO REGION (Iu)
A
B
C
18
INSTREAM USES
17
RECYCLE BETWEEN USES
10
SURFACE OUTFLOW FROM REGION (O_s)
11
UNDERGROUND OUTFLOW FROM REGION (O_u)
7
EVAPOTRANSPIRATION UNRELATED TO USE (E)
4
RELEASES FROM SURFACE STORAGE (R_s)
5
RELEASES FROM UNDERGROUND STORAGE (R_u)
6
EFFLUENT DISCHARGE TO STREAMS OR GROUNDWATER (D_f)
16
WITH-DRAWALS FOR USE (W)
8
ADDITIONS TO SURFACE STORAGE (A_s)
14
SURFACE STORAGE
12
CONSUMPTIVE USE (EVAPOTRANSPIRATION, CHEMICAL CHANGE, PRODUCT) (C)
13
EFFLUENT DISCHARGE TO SALT OR BRACKISH WATER (Ds)
9
ADDITIONS TO UNDERGROUND STORAGE (A_u)
15
UNDER-GROUND STORAGE

of the region).[3]

Ovals 8 and 9 are additions respectively to surface storage and to underground storage shown in circles 14 and 15. Such additions to storage, of course, come out of water availability in any given year. On the other hand, rectangles 4 and 5 show the releases from surface and underground storage and represent additions to water availability in the given year. Over the long run, these additions and releases sum algebraically to zero. A measurement of water amount at dial B therefore represents a flow regulated by storage.[4] Ovals 10 and 11 represent water flowing out of the region. Number 10 is surface outflow and number 11 is underground outflow. A measurement of water at dial C therefore represents water which is available for use within the region. It is assumed that some uses (INSTREAM USES) do not deplete this supply at all, but do prevent extreme levels of withdrawal.

The maximum amount of consumptive use, as well as the maximum amount of gross withdrawals, depends on several quantitative characteristics of the loop shown at the lower right of Figure 1. Triangle 16 is total withdrawals from surface and underground water flows. Of these withdrawals, a portion goes to consumptive use (the oval marked 12) where it is evapotranspirated through economic vegetation, incorporated in products, undergoes chemical change, or is evaporated during cooling back to the atmosphere. Another portion goes to oval 13. This represents effluent discharge to

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3. So may the other sources as well as evapotranspiration--these refinements will not be treated here, however.

4. The flow is the same in the long-run average as A, but with a different time configuration.

salt or brackish water which is not available for reuse; a portion as shown in rectangle 6 is effluent discharge to fresh water streams or groundwater. The dotted triangle 17 shows that a portion, at least, of this effluent may be recycled and again withdrawn.

It is, of course, possible to represent many of these quantitative relationships in simple algebraic form, and this may be very useful for examination of certain characteristics. Using the symbols listed in the various boxes, ovals, etc., the flows at the several dials can be represented as follows:

$$\text{Flow at A} = P + I_s + I_u - E \qquad (1)$$

$$\text{Flow at B} = P + I_s + I_u - E + R_u - A_u \qquad (2)$$

$$\text{Flow at C} = P + I_s + I_u - E + R_s - A_s + R_u - A_u - O_s - O_u \qquad (3)$$

Equation (3) comes closest to defining supply as "the amount at hand" for measurement purposes in the present study; however, there are several simplifications to be made. If equation (3) is transposed to put all "income" on one side and all "outlay" on the other, it becomes:

$P + I_s + I_u + R_s + R_u = E + A_s + A_u + O_s + O_u + C$ (4) where C is now considered as representing consumptive use.

However, over the long run, withdrawals and additions to storage must be equal (except for the possible mining of ground water which is excluded at this point); $A_s = R_s$, $A_u = R_u$. These, therefore, can be dropped from the equation.

In addition, surface flows and underground flows are so closely interdependent that it is safest to assume (given present knowledge) that the sum of surface and underground outflows is also constant; that is, that increases or decreases in either are reflected equally in the other. I and O consequently may be used without subscripts to represent measured inflow and outflow from a region.

Equation (4) can now be written simply as:

$$P + I = E + O + C$$

$$\text{or} \quad P - E + I = C + O \tag{5}$$

The right-hand side of equation (5) is the quantity of water available for consumptive use plus outflow from the region. Theoretically, this quantity could be increased by increasing P or decreasing E, but in humid areas such as Maryland it is not unlikely that measures to increase precipitation or lower non-economic evapo-transpiration would be economically attractive. Since no changes are assumed in P or E, the remaining way to increase C + O would be an increase in I, that is, higher inflows to Maryland from bordering states. Needless to say, this is extremely unlikely; in fact decreases are projected in I because of growing water demand in bordering states, and these are treated as an element of demand.

If the term C + O itself is considered, clearly C (consumptive use) can be raised if O can be lowered. The size of outflows from the State is set by several factors: the rights and needs of downstream users, the streamflow requirements for instream uses in the region, and the nature and arrangement of consumptive uses which determine the amount of "leakage."

Although most Maryland streams empty directly into the Chesapeake Bay or Atlantic Ocean, the city of Washington, D. C. is a major "downstream" user of water whose needs will continue to grow in the future. To an undefined extent, it is also necessary to maintain outflows of streams into their estuarial reaches to prevent quality problems. Thus no decrease in outflows due to decreased downstream requirements should be expected; on the contrary, an increase is projected for Region II, which is upstream of the District of Columbia.

The possibility may exist, however, of reducing instream requirements within a region, either by lowering the quality standards to be attained, or by requiring increased treatment of wastes before discharge into streams. This possibility will be examined in Chapter X when final demand and supply comparisons are made.

The third possibility - the increased efficiency of use of a given amount of water available for withdrawal - will be treated in the section to follow.

C. Consumptive use and withdrawal; reuse of water

How much water can be withdrawn from the quantity measured at point C in Figure 1, i.e., the quantity defined by equation (3)? How much consumptive use is possible from this quantity? The answers to these questions require analysis of the loop from withdrawal to effluent discharge to further withdrawal. In order to describe this cycle, two ratios are established. The first of these, r_1, is the ratio of D_f to W, that is, the proportion of gross withdrawals which is returned as effluent to fresh water streams or storage, or to groundwater. The second ratio, r_2, is the proportion of this fresh water effluent at any single use which is available for withdrawal at a subsequent time. This quantity is not shown explicitly in the diagram and will depend largely on the geographic distribution of uses within the basin. For the moment it may be assumed that within a region there is some average value of r_2.[5]

A numerical example may be useful at this point: Suppose that in a region the supply as defined by equation (3) is 800 units.[6] When water is withdrawn for use in agriculture, municipal systems, or industries, an average of 70 percent of the amount withdrawn is returned to streams or groundwater, though not in the same condition as at its first use, of course. Therefore, $r_1 = 0.70$. Users of water are so arranged in the region that of the amount returned in this fashion, 80 percent is available for use again; thus $r_2 = 0.80$.[7] At the first withdrawal, 800 units are taken; of this, 30 percent (240 units) is "consumed" during use, and 70 percent (560 units) is returned as effluent. Of this effluent, 20 percent (112 units) is unavailable for further use, although it is still in surface or subsurface flows of water. The remainder of the effluent (448 units) is once again withdrawn; of this amount, 30 percent (134 units) is "consumed" and the remaining 70 percent (314 units) is again returned as effluent. Of this amount, 20 percent (63 units) is unavailable for further use, and the remaining 251 units are once more withdrawn. The total amount withdrawn at all "rounds" approaches $\frac{1}{1 - r_1 r_2}$ times supply - i.e. $\frac{1}{1 - (0.7 \times 0.8)}$ or $\frac{1}{.44}$, which equals 2.273 times the 800 units originally available.

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5. The exposition which follows draws upon pp. 17-18, Water Supply, Economics, Technology, and Policy, Hirschleifer, DeHaven, and Milliman, University of Chicago Press, 1960.

6. Units may be either flows per unit time or volumes of water over an accounting period; there is no essential difference.

7. For the moment it may be useful to consider all the supply as concentrated at a single point, with users withdrawing water and returning 70 percent to the "pool" at each use. At each use, 20 percent escapes from the "pool".

In this example, therefore, total withdrawals can reach a maximum of 1,818 units. Since 30 percent of each unit withdrawn is "consumed", total consumptive use can reach a maximum of 545 units. Consumptive use therefore approaches a maximum of $\frac{1 - r_1}{1 - r_1 r_2}$ times supply.

If, at this stage, a constant flow level and the absence of quality problems are assumed, the maximum withdrawals and consumptive uses from a given available quantity of water depend on the levels of both the ratios, r_1 and r_2, as shown in Figures 2 and 3. The most significant conclusion to be drawn from Figures 2 and 3 is that changes in the size of either r_1 or r_2 produce large changes in total withdrawals only at fairly high values and only when the other ratio is also fairly high - say 0.7 or greater. These relations are used here solely to evaluate relative sizes of total withdrawals and consumptive uses.

D. Probability distributions of water availability over time

The important component of the hydrological cycle consisting of water flowing in streams is subject to extreme fluctuations over time, and these time periods vary from one day, at the least, to several years in length. For example, Table 1 shows mean daily flows, standard deviations of flows, and the ratio of the two at one gaging station on the Monocacy River near Bridgeport, Maryland, averaged for periods from one day to one year, and for flows smoothed by 7-day moving averages.

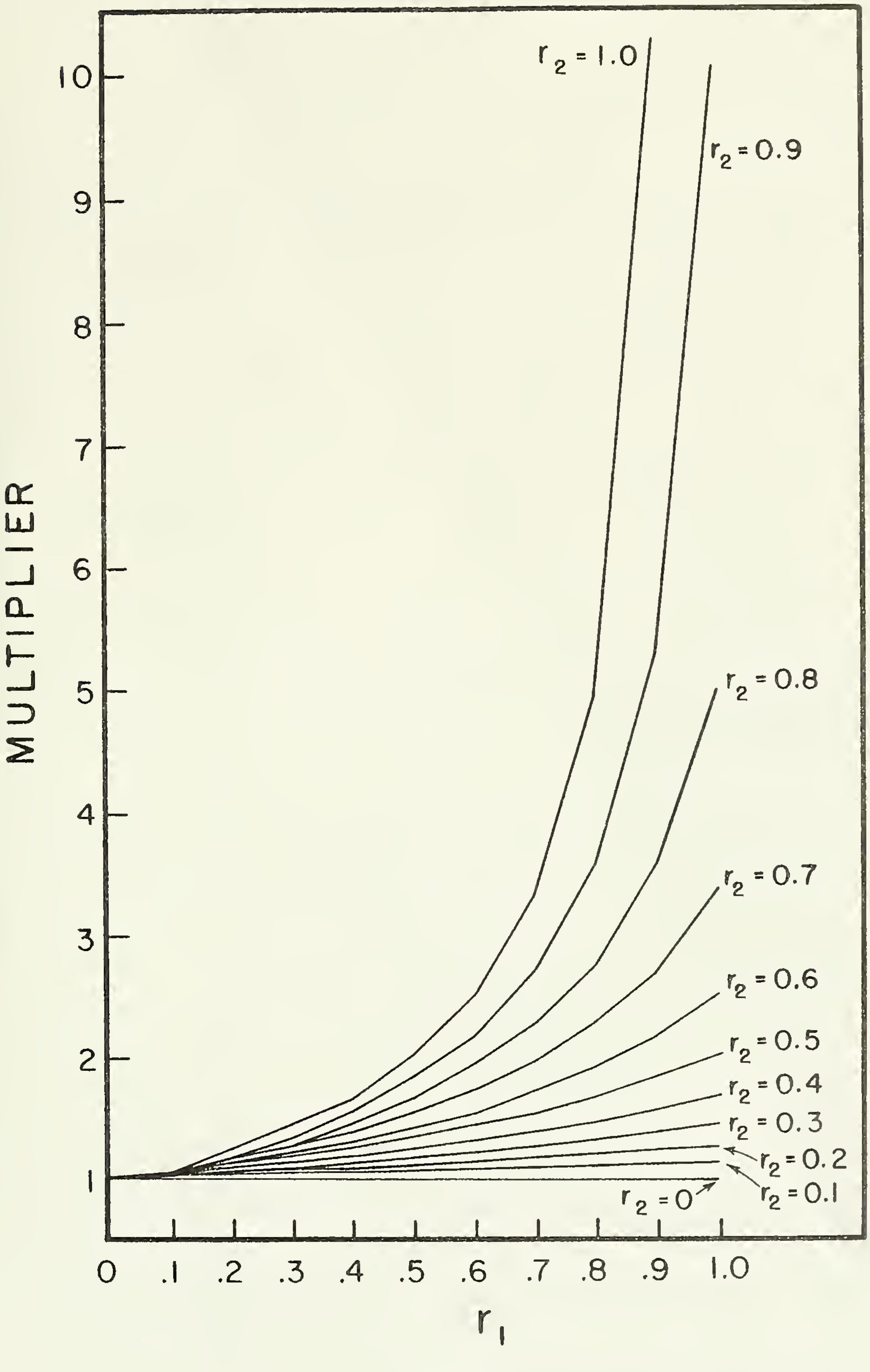

Figure 2

Withdrawal Multipliers for Alternative Values of r_1 and r_2

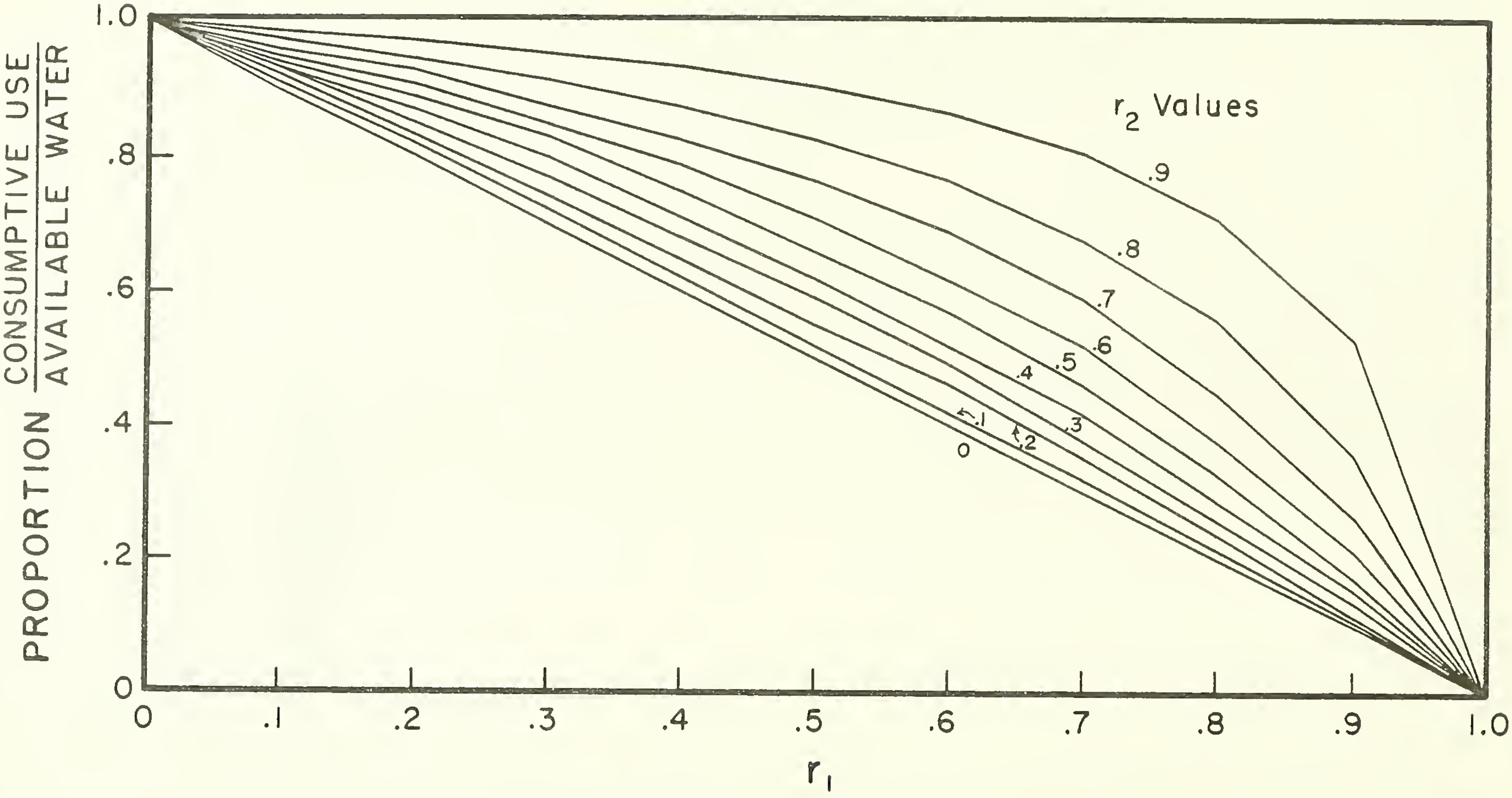

Figure 3

Consumptive Use as Proportion of Quantity Available. Alternative Values of r_1 & r_2

TABLE 1

Variation in Flow - Monocacy River near Bridgeport, Maryland

Time Period Over Which Daily Flows Were Averaged	Length of Record of Flows	Daily Mean Flow (cfs)	Standard Dev. (cfs)	Coefficient of Variation $\left(\frac{\sigma}{\text{Mean}}\right)$
1 Day	92 days-July 1 to Sept. 30, 1959	22.3	31.1	1.394
7 Days	Moving averages-July 1 to Sept. 30, 1959	22.8	19.6	0.859
1 Month	156 Months-Jan. 1943 to Dec. 1955	197.9	116.7	0.589
1 Year	13 years-1943 to 1955	197.2	58.2	0.295

Source: Computed from United States Geological Survey Water Supply Papers

The customary way of presenting the variation in streamflows is to plot recorded data in a cumulative frequency (flow duration) curve such as that shown in Figure 4. The shape of this curve gives an indication of the form of the frequency distribution of recorded flows. To further facilitate comparison of the distribution with normal or log normal distributions, the curve may be plotted on probability papers. Figure 5 shows the same data as Figure 4 plotted on logarithmic probability paper; if it were an exactly log-normal distribution, the plot would be a straight line.

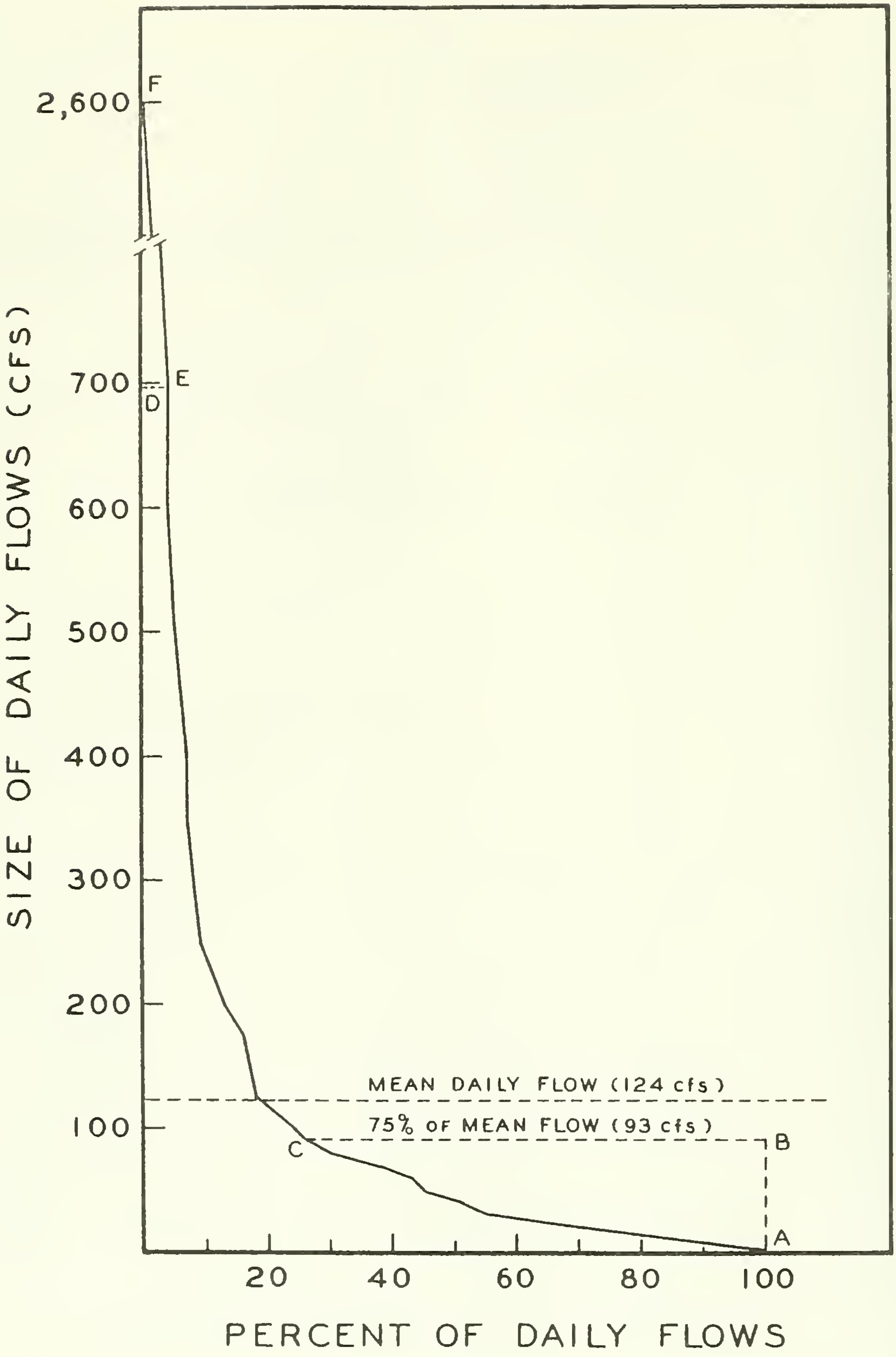

Figure 4

Cumulative Frequency of Daily Flows Equalled or Exceeded,
Monacacy River, Bridgeport, Maryland
(Sample, Water Year 1958-59)

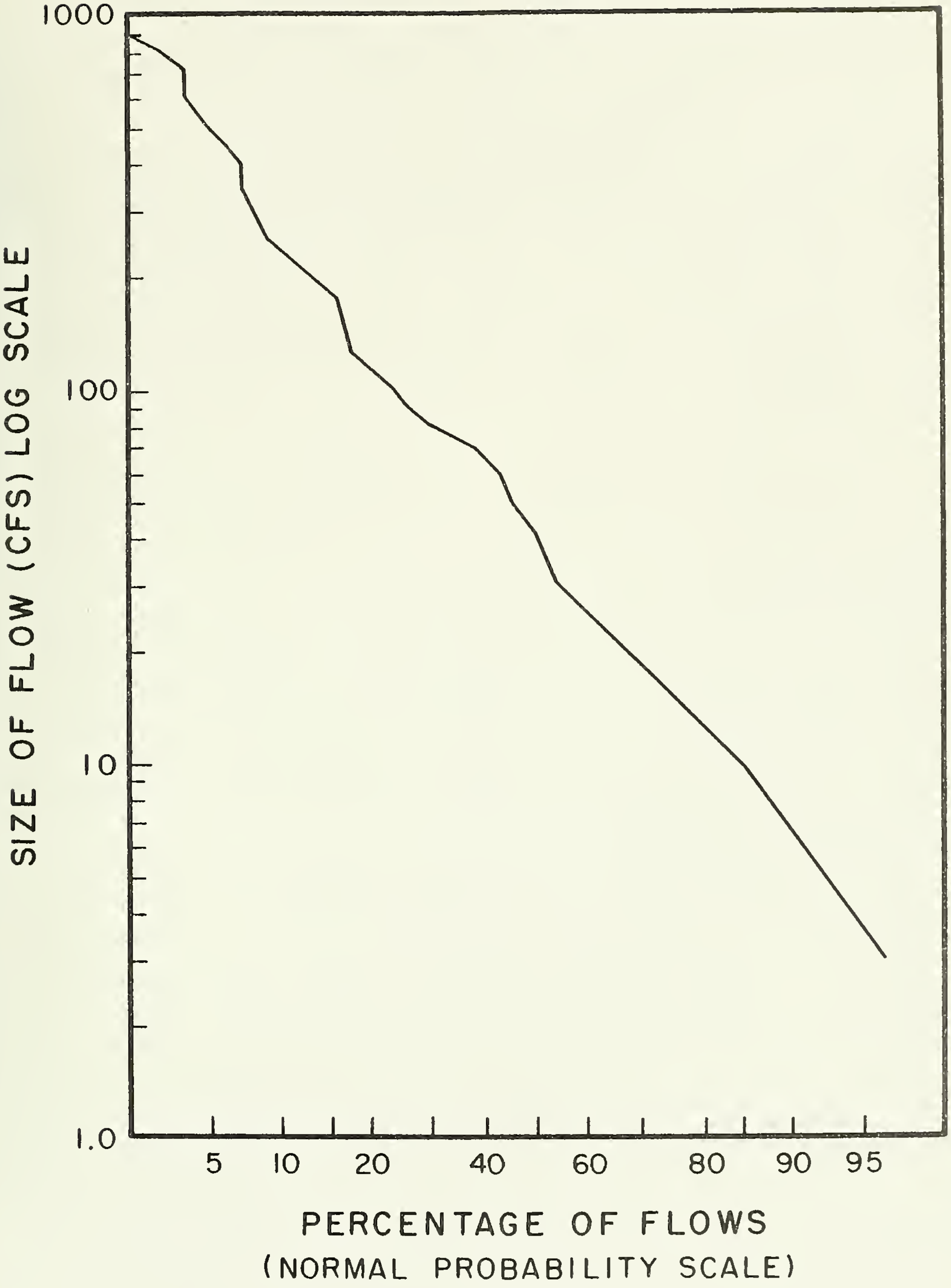

Figure 5

Data of Figure 4 Plotted on Logarithmic Probability Paper

From Figure 4 it is possible to read directly the flow which is equaled or exceeded in any specified percent of the time (for example, 50 percent of daily flows are 40 or more cubic feet per second). The level used most extensively in this study to represent flows presently available is that flow equaled or exceeded 95 percent of the time. We also present the smaller figure representing the seven-consecutive-day average equaled or exceeded in nine years out of ten (7-day, 10 year). This latter measure was employed by the Army Corps of Engineers in the Potomac Basin Study.

Table 2 shows the sum of flows in all streams from each Maryland region, flowing at their mean level, and at the 95 percent and 7 day-10 year levels. This Table also records flows separately, in major rivers which form boundaries between regions, or between a region and other states. Water in these streams represents a joint supply to be shared between regions or states in ways which are discussed in Chapter X. The detailed streamflow data upon which Table 2 is based are given in Appendix C.

E. Storage-yield relations

Society commonly regards water supply as the amount of water on which it can depend. The factor influencing this point of view is the variability of flows. Reduction of this variability is an objective which, when realized by any means, results in an increase of water dependably available. The construction of dams behind which high flows can be stored for release during low flow periods is such a means.

TABLE 2

Aggregate Stream Flows, by Maryland Regions (m.g.d.)
Means and Alternative Low Flows

Region	Mean Flows of Record	Flow Equaled or Exceeded 95 Percent of Time	7 Consecutive Day Mean Flow with 10 Year Recurrence
I. Southern Maryland			
Streams leaving Region	355.2	31.1	24.7
II. Western Maryland			
Streams North of Potomac	2,286.1	258.6	159.7
Streams South of Potomac	4,162.4	557.8	287.2
Ohio Basin Drainage	667.8	87.8	46.1
III. Baltimore Metropolitan			
Streams leaving Region	1,567.1	475.9	315.8
Susquehanna River flow	27,187.0	3,262.0	2,229.3
IV. Washington Metropolitan			
Streams leaving Region	576.1	79.4	35.7
V. Eastern Shore			
Streams leaving Region	1,659.8	314.8	192.4

One way in which the process may be visualized is seen in Figure 4, where the dashed line indicates the mean flow of record; this is approximately 124 c.f.s. for the stream represented. In order to raise the minimum flow to 75 percent of the mean flow (93 c.f.s.), the low end of the curve must be raised to line CB in Figure 4, which requires a volume of storage equal to area ABC. This storage could be filled by cutting down the high flows by an equivalent amount (area d.e.f.) to a maximum of 695 c.f.s.

To determine storage requirements simply by this method, however, would be to ignore two important elements of the problem - and, in general, to misestimate storage requirements. First, because storage reservoirs may be refilled by any high flows which might occur between low flows, the capacity of storage usually need not be enough to raise all the deficient flows to a desired level; the chronological sequence of flows is therefore a variable of critical importance in determining flow-storage relations. Secondly, the recorded flows for any stream rarely if ever represent the full range of possible variation in that stream's flows. There is an increase in variation as the length of record increases, implying that the period of record can best be regarded as a sample drawn from a statistical population of possible flows for a specific stream.[8] Since this results in increased variation as well as an increased probability of long sequences of low flows, a statistical treatment raises the storage requirement

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8. See discussion in Chapter One of Operations Research in Water Quality Management, Harvard University Division of Engineering and Applied Physics, February 1963, Cambridge, Massachusetts.

except where stream records are longer than the expected life of storage facilities. Such a treatment also makes it possible to develop synthetic hydrologies for specific streams and develop probability distributions of storage requirements, although it is not possible within the scope of this study to pursue these possibilities.

Instead, calculations, based on unpublished computations of the U. S. Corps of Engineers, are made for three Maryland regions to determine the storage requirements required to raise the low flows to specified levels. For a number of possible reservoir sites in the Potomac Basin, the Corps developed relations between amount of storage (in acre-feet per square mile of watershed) and flow volume (in cubic feet per second per square mile of watershed). Using this relation, we calculated the flow expected on each major stream for a schedule of reservoir sizes; from each of these flow levels we subtracted current 95 percent flows to derive flow increases for each reservoir size. For each reservoir size, flow increases on all streams were summed and plotted against the total amount of storage represented by these reservoirs. The resulting storage-yield relation is given in Figure 6.[9]

Storage-yield relations apply only in Western Maryland, the Baltimore Metropolitan Region, and the Maryland portion of the Washington Metropolitan Region, since only these regions lie wholly or partly in physiographic provinces where reservoir storage is feasible. The remaining two regions,

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[9] The relation conforms very closely to the quadratic equation $S = -7400 + 563.5\ Y + .375\ Y^2$, where S = storage required (in acre-feet) and Y = yield increase (in millions of gallons per day).

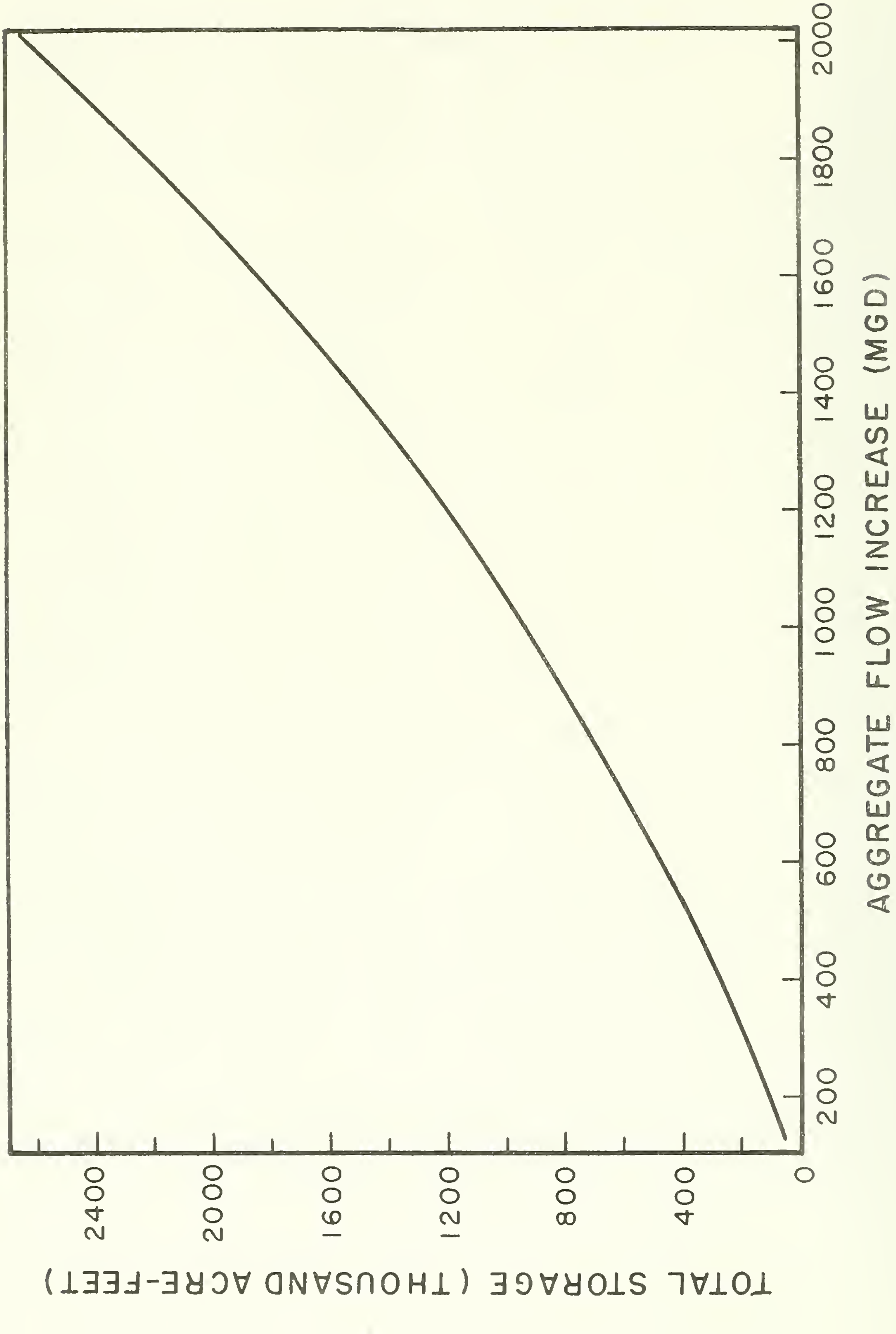
TOTAL STORAGE (THOUSAND ACRE-FEET)
2400
2000
1600
1200
800
400
0
200
400
600
800
1000
1200
1400
1600
1800
2000
AGGREGATE FLOW INCREASE (MGD)

Figure 6

Southern Maryland and the Eastern Shore, are on the coastal plain where porous soils and lack of relief make such storage impracticable. In these regions, however, ground water is much more available, and these will be treated in a separate section.

Combining the storage-yield relation (Figure 6) with the storage cost curve (Figure 7) we can construct a yield-cost curve - that is, a curve (Figure 8) showing the annual costs involved in raising low flows by varying amounts. This can be regarded as an economic supply curve of quantities (above existing levels) related to costs.

F. Costs of storage

As indicated in the previous Section, the only feasible reservoir sites in Maryland are in the Washington, D. C. Region (IV), the Baltimore Region (III), and Western Maryland (II). Of these Regions, the Baltimore Metropolitan area is the most severely limited, since most of the desirable sites have already been developed. Because almost all of the feasible sites fall within the Potomac River Basin, they have been the subject of study in the Corps of Engineers' Potomac River Basin Report. Investigating a large number of potential sites, the Corps recommended six Maryland reservoirs in their plan. One of these, at Seneca, is in Region IV and the other five are in Region II. For each of these sites, graphs were made available showing initial reservoir cost as a function of thousands of acre feet of storage capacity.

These have been aggregated into regional cost-storage relationships in Table 3. For Region IV, the data refer only to the Seneca project.

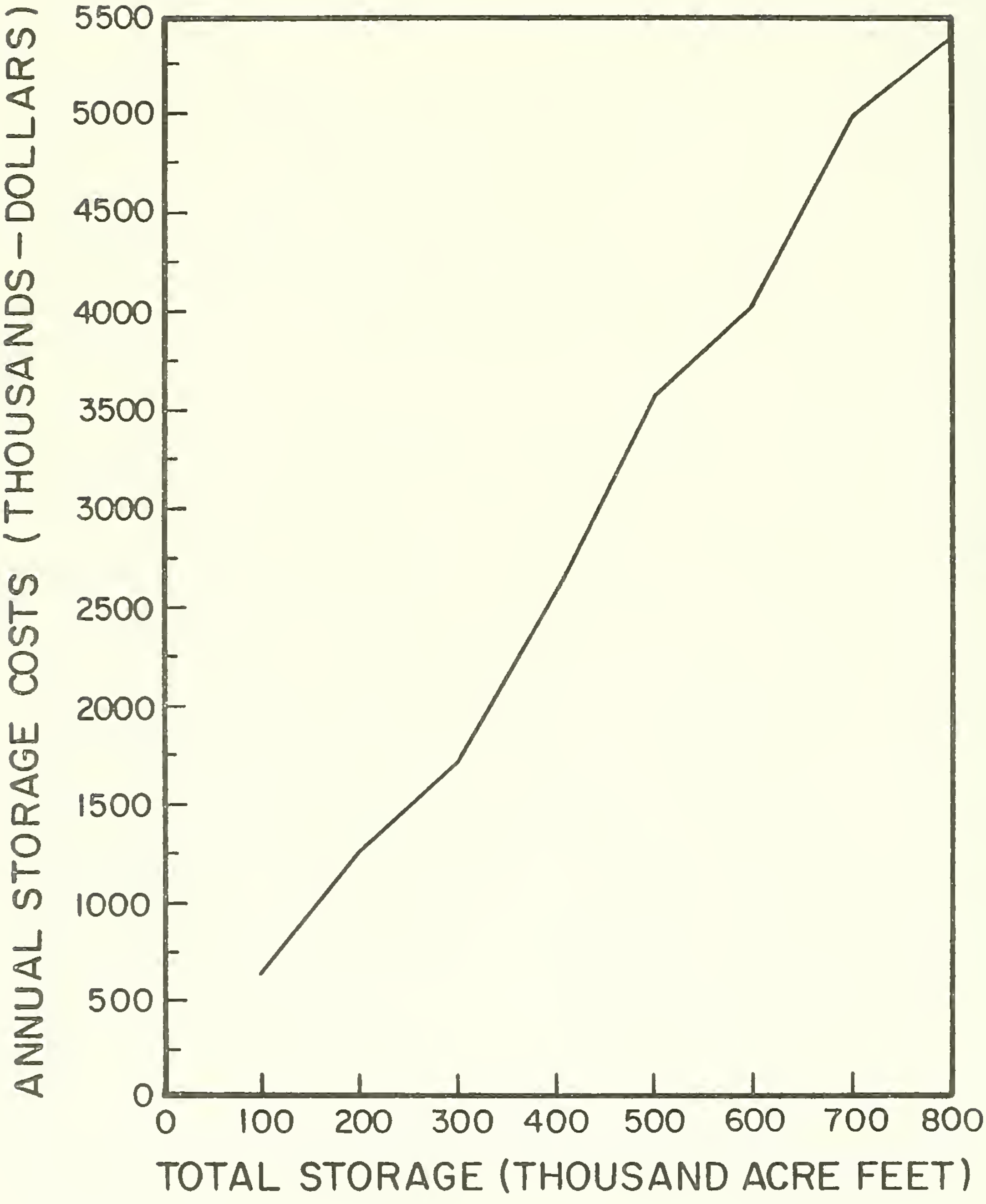

Figure 7

Storage Costs (Annual Basis), Potomac Basin in Maryland

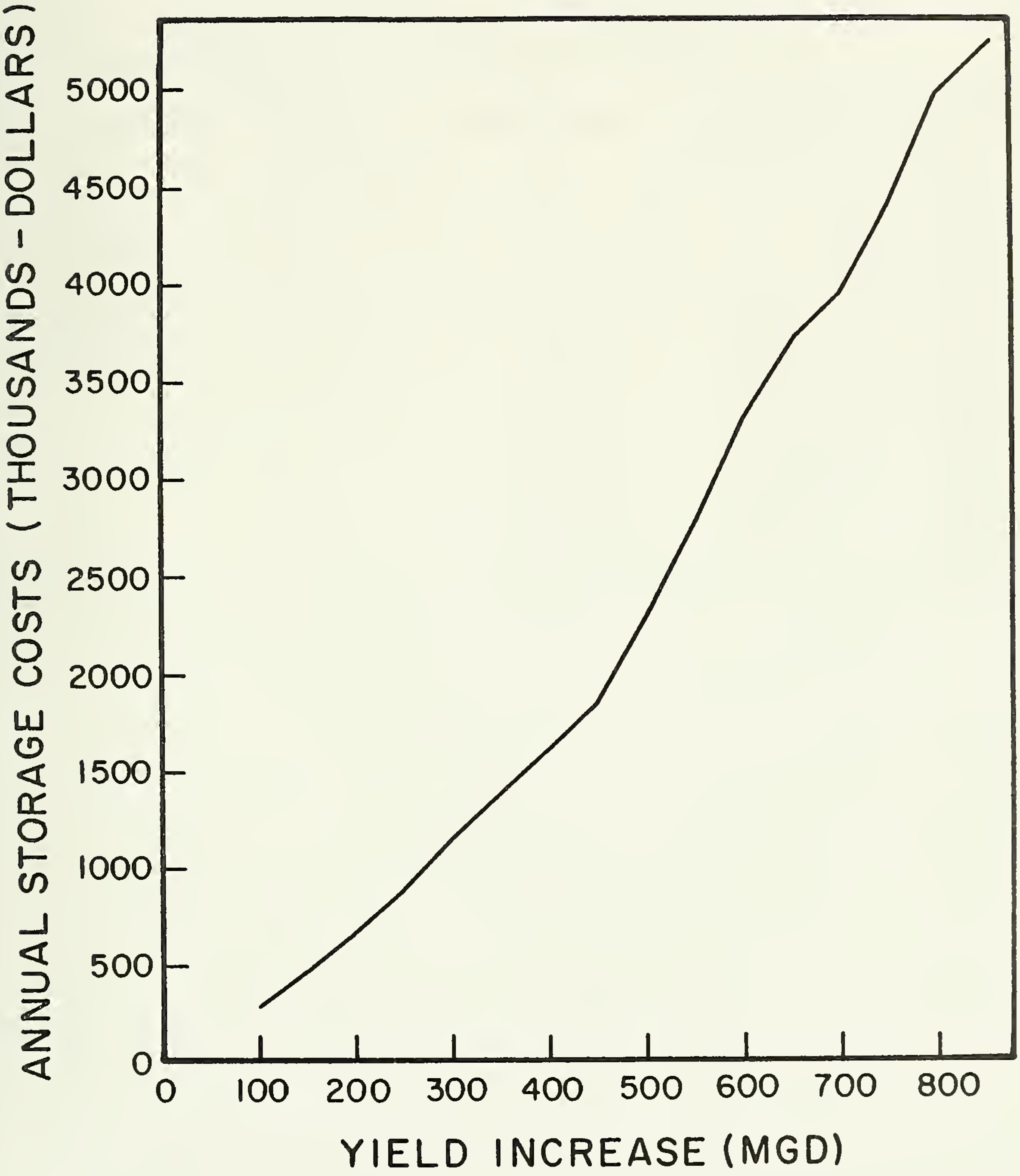

Figure 8

Cost Curve for Yield Increases, Potomac Basin

TABLE 3

Maryland Reservoirs Storage Costs

Storage (000 A.F.)	Region IV - Washington Metropolitan (Mil. Dol.)	Region IV - Washington Metropolitan (Thous. Dol.)	Region II - Western Maryland (Mil. Dol.)	Region II - Western Maryland (Thous. Dol.)
100	--	--	9.3	644.3
200	--	--	18.1	1,249.7
300	--	--	24.6	1,700.0
400	--	--	37.2	2,569.4
500	46.7	3,221.4	51.6	3,563.0
600	54.3	3,749.3	58.5	4,036.5
700	60.7	4,191.7	72.1	4,975.7
800	65.2	4,502.2	78.1	5,387.2
900	70.9	4,890.4	--	--
1,000	76.5	5,278.5	--	--
1,100	82.1	5,666.6	--	--
1,200	87.7	6,054.7	--	--
1,300	92.2	6,365.2	--	--
1,400	96.2	6,636.9	--	--
1,500	99.5	6,869.8	--	--

Source: Derived from Corps of Engineers, unpublished data.

For Region II, the site yielding the cheapest storage was chosen for the first entries in the table. Successive entries are obtained by including more costly sites. Initial costs have been converted to annual costs using an interest rate of 4 percent, and operating and maintenance costs have been added.

G. Groundwater supply

In two Maryland Regions, the Eastern Shore (Region V) and Southern Maryland (Region I) we have noted previously that storage, except in very small ponds, is not feasible, and that the prime source of water beyond existing streamflows will be groundwater. Parts of the Baltimore and Washington Metropolitan areas (Regions III and IV) also lie on the coastal plain where groundwater is relatively abundant. A considerably smaller amount of groundwater is also obtainable on the Piedmont areas of Regions II, III, and IV.

Estimates, from various sources, of groundwater supplies (that is, amounts which will be replaced by natural recharge over long periods) are presented in Table 4. These supplies are not equally accessible for development, however, because of differing depths and rock overlays.[10]

There is no attempt to develop cost-yield relations for groundwater supplies in this report; this is partly because considerable data collection would be required, and partly because in the two Regions where groundwater is or will be the primary source, the alternatives of surface water development or increased waste treatment are not feasible or relevant. It is possible, however, that importation of water from other regions would be economically feasible.

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[10] Data in Vol. VII of the Corps of Engineers' Potomac River Basin Report indicate that well drilling costs alone vary from $6,400 to $34,000 per m.g.d. in the Potomac Basin.

TABLE 4

Groundwater Supplies by Maryland Regions

Region	Supply (m.g.d.)	Source of Data
I. Southern Maryland	324[a]	Bulletin #15, Maryland Department of Geology, Mines and Water Resources
II. Western Maryland	95	Vol. VII, Corps of Engineers' Potomac River Basin Report
III. Baltimore Metropolitan	200	Vol. VII, Corps of Engineers' Potomac River Basin Report (Estimated portion of Maryland Coastal Plain supply lying in Prince George's County)
IV. Washington Metropolitan	200[b]	Bulletin #26, Maryland Department of Geology, Mines and Water Resources Bulletin #4, Maryland Department of Geology, Mines and Water Resources
V. Eastern Shore	960[c]	Bulletin #18, Maryland Department of Geology, Mines and Water Resources Bulletin #16, Maryland Department of Geology, Mines and Water Resources Bulletin #21, Water Resources of Cecil, Kent, Queen Anne's Counties

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[a] An estimated 8.5 m.g.d. is now being pumped.
[b] An estimated 40 m.g.d. is now being pumped.
[c] An estimated 26.5 m.g.d. is now being pumped.

CHAPTER X

DEMAND AND SUPPLY COMPARED

A. Introduction

Choice is a governing factor in the following discussion of meeting Maryland's water demands.

Because substantial uncertainty underlies certain aspects of this study, the issuance of a single prescription for the meeting of water demands is impossible. Moreover, such a selection from various alternatives would be undesirable, for this responsibility is properly borne by those who represent the State in policy-making positions. Therefore, no single set of water demands is predicted, and no one policy to meet these demands is recommended. Rather, ranges of demands under varying conditions are presented, with an attempt to specify the monetary costs of alternative public policies.

The element of uncertainty is particularly evident in two areas of this report, for a.) population and employment projections by Region depend upon a host of factors on which it is only possible to make reasonable guesses and b.) capacity of streams to assimilate wastes depends upon a complex physical process about which relatively little is known.

Matters on which the public may reasonably make choices are the degree of treatment to be required of those who dispose of wastes, the amount of storage to be built for low flow augmentation and the quality level at which streams are to be maintained.[1] In making these choices, certain intangible political, aesthetic, and subjective considerations are very important; it is no less important to ascertain the orders of magnitude of the monetary costs involved in different policy choices, and under different outcomes of the elements of uncertainty.

Accordingly, we estimate as far as possible the costs which may be expected from a number of combinations of future outcomes and policy choices - from a combination of high population increases, low stream assimilation capacities, low treatment requirements, and high quality standards, to that with low population increases, high treatment requirements and lower quality standards.

This Chapter proceeds as follows: Section B discusses the analytical tools employed and gives overall dimensions of substitutability among treatment levels, storage for quality maintenance, and quality standards, in monetary terms. Section C deals with each Region of the State, comparing demands and supply in each under various alternatives. Section D provides a brief evaluation and summary of the findings, and a discussion of certain problems which have necessarily been excluded from close scrutiny in this study.

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1. Another policy area consists of the degree of risk which is judged acceptable in defining supply, since streamflows are subject to wide variation. We have confined analysis to a supply defined as aggregate flows available 95 percent of the time. A supply concept which does not accept the risk of deficiencies 5 percent of the time, or which includes a minimum duration of low flows, would imply increased costs, either of treatment or storage, to achieve the same quality.

B. Alternative ways of achieving supply - demand balances

We are chiefly interested in estimating the effect of alternative policy choices which entail varying required levels of waste treatment and, consequently, different amounts of storage to raise streamflow. This effect is measured as the sum of treatment and storage costs. The variation of this sum coincident with changes in standards of stream quality is also examined. However, as emphasized throughout, there are also considerable areas of uncertainty in the analysis; these, of course, affect the sum of costs as well. At the outset of this section then, these uncertain elements - population projections, waste assimilation levels of streams - will be held constant, while the cost effects of policy substitutions are analyzed. Later on, the uncertainty factor is again introduced.

The chain of causation from an increase in required treatment level sufficient to add one dollar to treatment costs, to a consequent decrease in storage costs is as follows: a.) The increase of one dollar's worth of treatment reduces waste discharged to streams; b.) less waste in the stream requires a smaller flow to maintain a specified standard of dissolved oxygen content; c.) a smaller flow requires a smaller amount of storage; d.) this reduction in storage volume implies a saving in storage cost. All the parts of this chain have already been described in Chapters VII or IX except a.), the cost relations for waste treatment at specified percentages. A discussion of this aspect follows.

The cost of sewage treatment as estimated here consists of 1.) construction costs, and 2.) plant operation and maintenance costs. Collection costs are omitted; the U. S. Public Health Service estimates that these costs are about $1.30 per urban person per year. This figure, as well as the estimates of construction costs, are in 1960 dollars.

The source for the calculations of construction costs is the Water Pollution Control Commission Journal article of June, 1960 by Rowan, Jenkins and Butler, "Sewage Treatment Construction Costs." The authors consider contract costs of the plant alone. "The cost of interceptor and outfall sewers, pumping stations not contiguous to the plant structure, and administrative, legal, fiscal, land and engineering costs have been excluded." They state, however, that "Experience under the Federal Construction Grants Program has demonstrated that construction contract costs represent about 80 percent of the total first cost of sewage treatment plants."

Operation and maintenance costs are estimated from the Rowan, Jenkins and Howells article of the February, 1961 Water Pollution Control Commission Journal, "Estimating Sewage Treatment Plant Operation and Maintenance Costs." Operation and maintenance costs as defined therein "do not reflect costs for general administration, capital improvement, or other items not directly related to plant operation."

Cost data in the article represent the experience of more than 300 plants for the years 1955-58. No adjustment to 1960 prices was attempted nor, indeed, considered necessary because a.) the index number problem involved was not worth the possible small increase in accuracy; b.) rises in wages - a substantial part of operation and maintenance costs - have tended to be offset in this kind of operation by reduction in labor force.

Cost curves for three sizes of plants are given in Figure 1.[2] Primary plus activated sludge treatment was estimated to reduce biochemical oxygen demand 90 percent; primary plus trickling filter treatment was estimated to remove 85 percent BOD. We recognize that certain other alternative treatment systems exist - in particular the lagooning of wastes to allow discharge during periods of high streamflow. It is possible that costs given here might be lowered in areas where low land costs have made lagooning feasible.

Figure 2 presents the rate of substitution between dollars spent for treatment and dollars spent for storage in order to maintain a given stream quality of 5 parts per million (p.p.m.) when total untreated wastes of 1,000,000 population equivalent (p.e.) are discharged to streams with flows of 258 million gallons daily (m.g.d.), and when a waste assimilation level of 400 p.e./m.g.d. is assumed.[3] This figure, therefore, illustrates once more that expenditures on storage and on waste treatment are alternative ways of maintaining a given stream quality. The solid line is an isoquality line, that is, it represents combinations of outlays for treatment and storage which maintain water at a minimum of 5 p.p.m. dissolved oxygen. Note that the achievement of higher quality (say 6 p.p.m. minimum) would be shown by a different isoquality line above the one on Figure 2; achievement of lower quality (say 4 p.p.m.) would be shown by a new line below the one in the figure.

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[2] Tables giving the elements of cost estimates are given in Appendix D.

[3] The assumption is also made that one-half of the wastes are municipal, and bear a collection cost of 1.30 per p.e. These annual costs assume a 50-year life of both storage and treatment facilities.

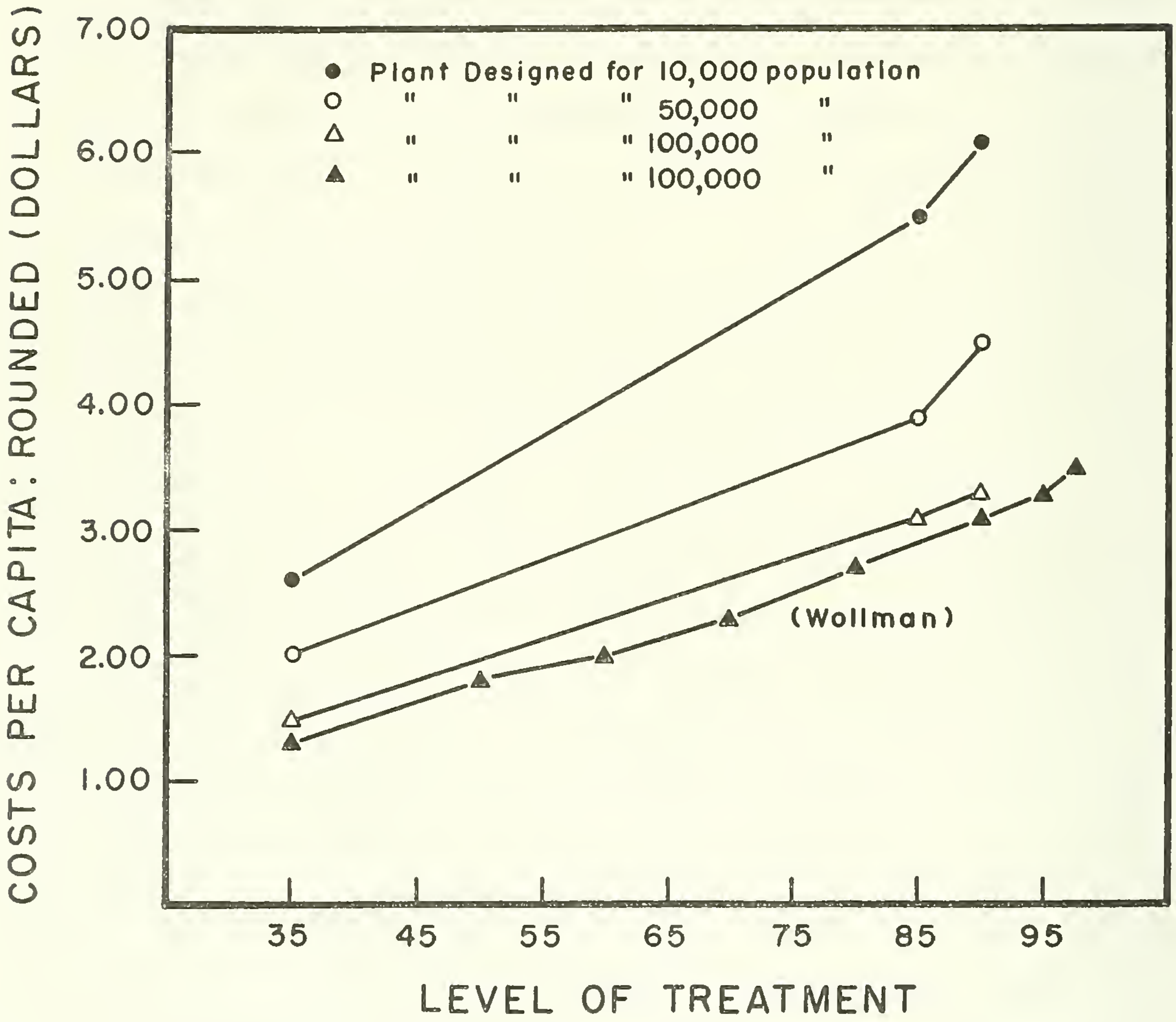

Figure 1

Per Capita Treatment Cost Curves

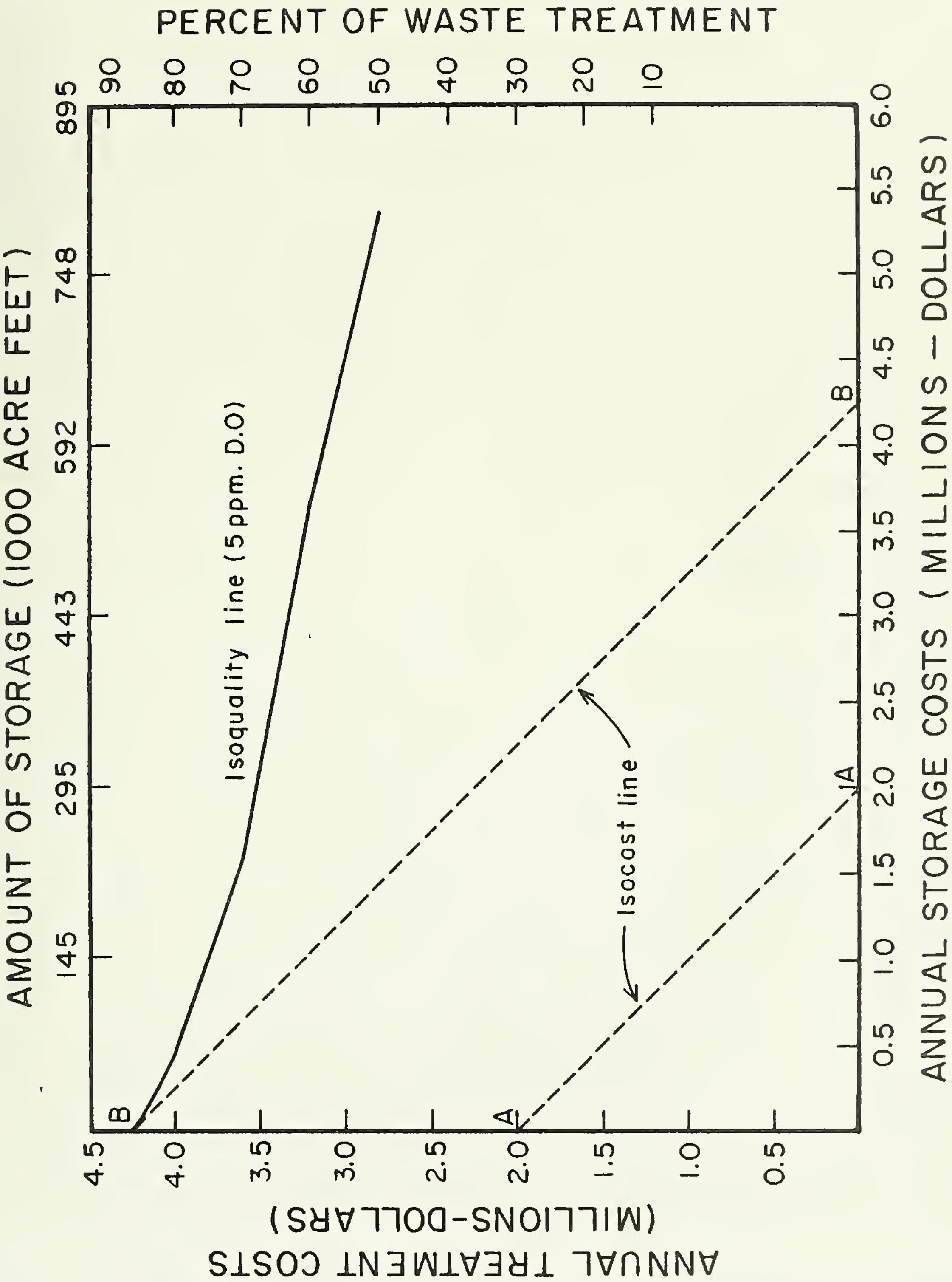

Figure 2

Substitution in Quality Maintenance

Below the isoquality line we have shown two dashed lines, marked "isocost lines." For each of these lines, every point represents a fixed amount ($2.0 million for line AA and $4.2 million for line BB) of total costs of treatment and storage. Line BB just touches the isoquality line at its left end, indicating that the least-cost combination of expenditures on treatment and storage which achieves the desired quality is that represented by $4.2 million spent on treatment and nothing spent on storage. Reading from the scale at the right side of Figure 2, the corresponding treatment level is 86 percent and from the scale at the top of the figure, of course, no storage would be required. Before concluding that this is an optimum combination which we should use for projections, an examination is necessary of the effects upon the isoquality curve of changes in quality standards, population projections, and assimilation levels.

Figure 3 shows the effect of changing population and employment projections, thereby changing the untreated waste loads in the system. The isoquality curve shifts downward, so that total costs are less for all combinations of treatment and storage; note, however, that the curve shifts only vertically and that the slopes of all segments of the curve remain the same. This means that the optimum amount of storage is still zero, while the optimum treatment level drops to about 18 percent. Conversely, increasing population and wastes would still leave optimum storage at zero level, while raising optimum treatment levels. The treatment level, but not the storage volume, is a function of population (other factors held constant);

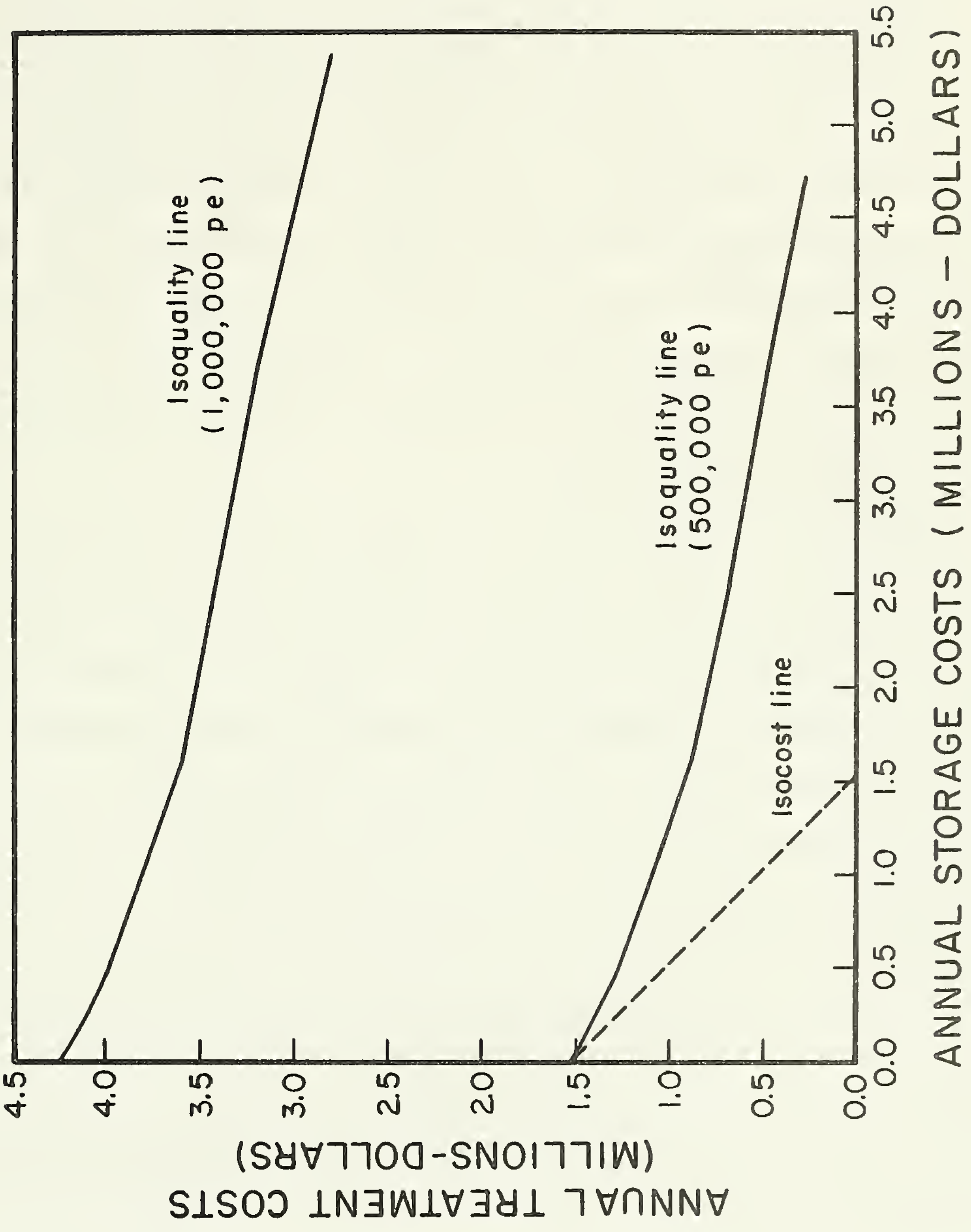

Figure 3

Effect of Changes in Waste Load on Quality Maintenance Costs of course, upper limits on treatment levels would require storage as well for larger populations and pollution loads.

Let us now hold population constant, but examine the effects of changes in the assimilation capacity assumed for streams: In Figure 4 are shown the low, medium, and high levels employed in the study (217, 400, and 650 p.e./m.g.d. respectively). In this case, successively lower assimilation capacities change the slopes of all segments of the isoquality curve. Only with an assimilation capacity of over 1500 p.e./m.g.d. would storage be included in a least-cost combination. Treatment levels of from 77 percent to 92.5 percent are indicated for the low to high range of assimilation capacity assumptions used here.

Finally, what is the effect of varying the quality standard to be maintained in streams? In Figure 5, both the previous 5 p.p.m. isoquality curve and a less stringent 4 p.p.m. curve are shown. Since a change in quality standard is mathematically equivalent in these calculations to a change in assimilation capacity, the same effect is noted here: the slopes of both segments of the curve change, and the entire curve shifts downward, but with the break points at the same horizontal positions. In other words, lower quality standards would reduce total costs and the required treatment levels, but leave storage requirements at zero for the least-cost combination. Raising quality standards (holding other basic assumptions constant) would eventually result in an optimum including some storage, but at maximum treatment levels and high costs.

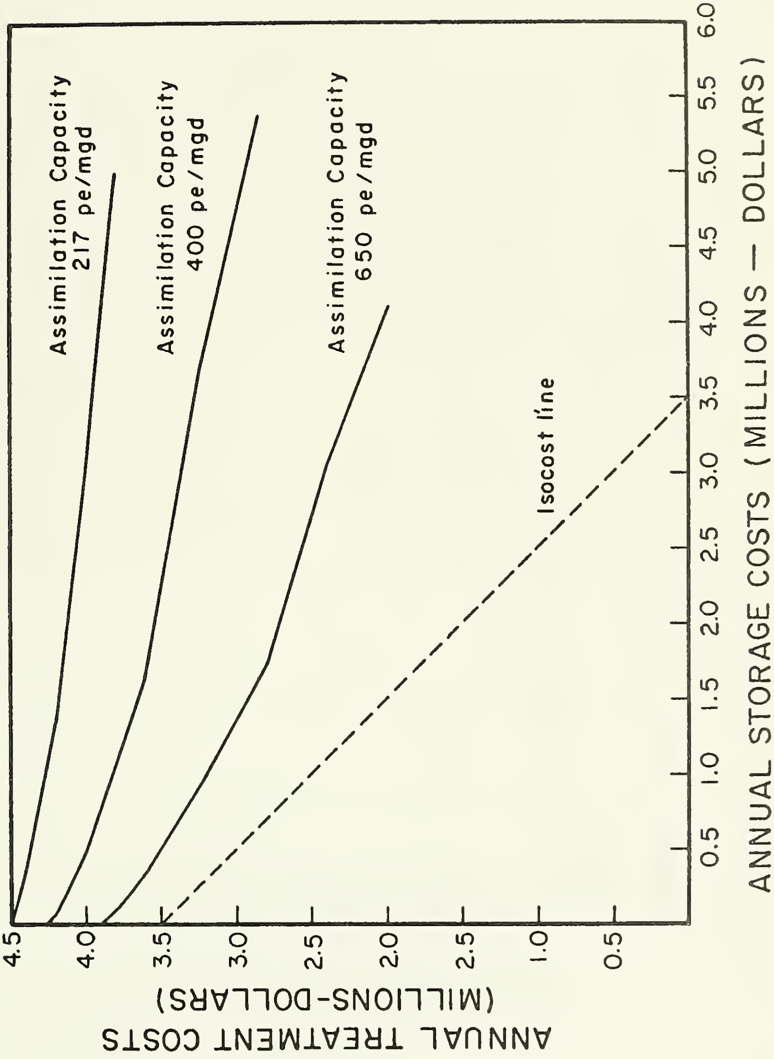

Figure 4

Effects of Changes in Assumed Assimilation Capacity on Quality Maintenance Costs

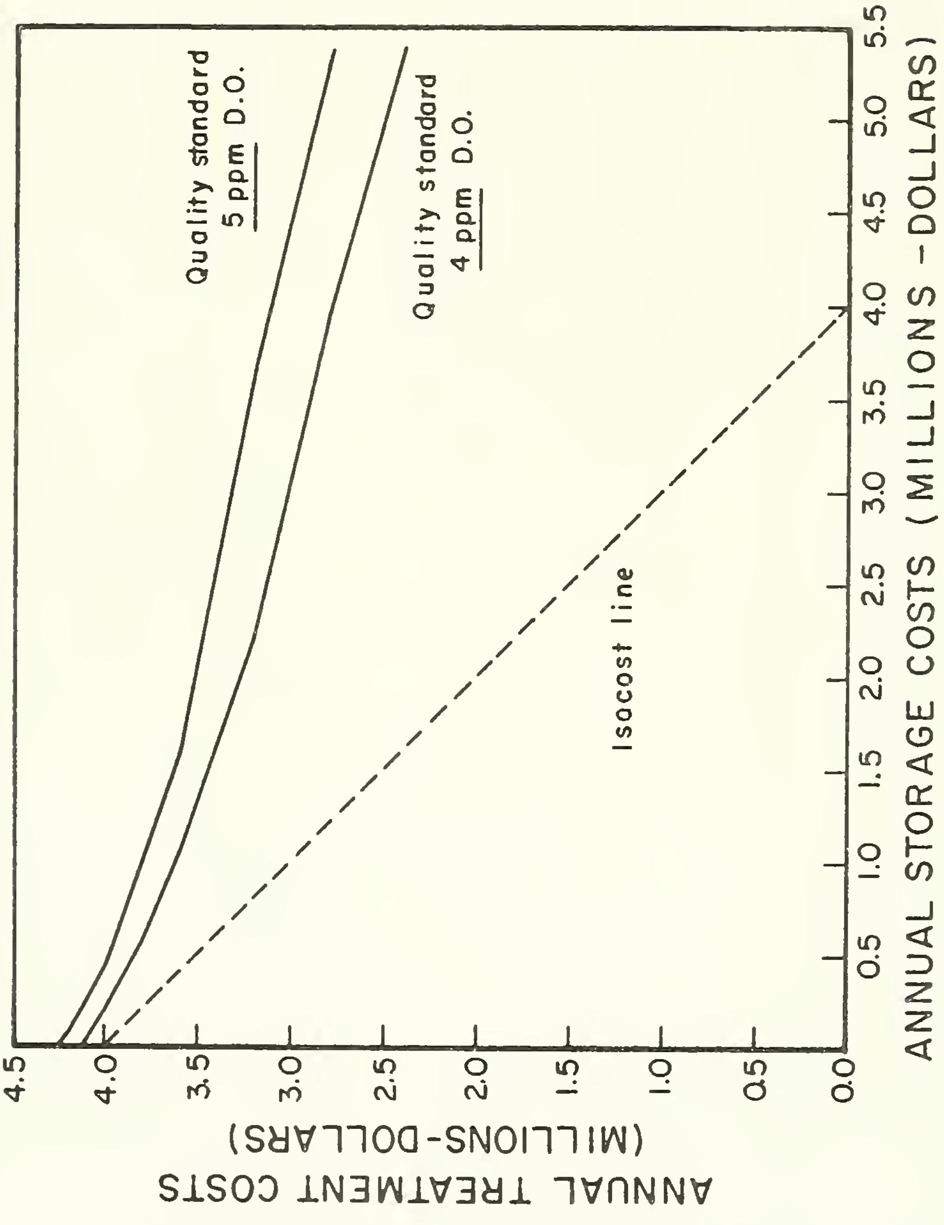

Figure 5

Effect of Changes in Quality Standards on Quality Maintenance Costs

Under what we believe to be the most reasonable set of assumptions, namely this report's medium population projections and medium assimilation capacity, the optimum combination would be no storage and fairly high treatment levels, the exact level of which would vary somewhat according to total waste loading. Accordingly, we carry through the analysis one high level of treatment which approximates the minimum cost method of achieving quality standards. A lower treatment level is also evaluated because it may be far more likely to be achieved, in the face of political and technological realities.

C. Region by Region supply - demand balances

1. Region I - Southern Maryland

This Region, consisting of St. Mary's, Charles, and Calvert Counties lies entirely on the coastal plain to the south and east of the District of Columbia. It is bordered by salt or brackish water on three sides - the Potomac estuary to the west and south, the Chesapeake Bay to the east.

At present the area is heavily agricultural and quite sparsely populated (84 persons per square mile, compared to the statewide average of 314 per square mile). This report's projections anticipate a relatively high rate of population growth (a tripling by 2010) and some industrialization. This is due both to the Region's proximity to Washington, D. C., and to its long shoreline which offers both tidewater industrial locations and recreational opportunities.

Table 1 summarizes projected water supply and demand for Region I in 1970, 1980, and 2010. From Table IX - 2, the freshwater streamflow available 95 percent of the time is 31.1 million gallons per day; because of the way in which this quantity was calculated, it is largely the net of existing consumptive uses. For each projection period we can, therefore, compare additional projected consumptive uses (see Tables, Chapter VIII) with the 31.1 m.g.d. supply. This is done in the first five rows of Table 1. By 1980, projected use increases require nearly all of the 95 percent streamflow, while by 2010 a deficiency of some 45 m.g.d. occurs.

Because it is assumed that all wastes after treatment in Region I will be discharged to salt or brackish waters, there is no projected demand for water flowing in streams to maintain quality standards.

There is, however, a sizeable additional source of supply in the estimated 315 m.g.d. rechargeable groundwater shown in row six of Table 1. Although (as pointed out in Chapter IX) the cost of obtaining groundwater has not been calculated, it would undoubtedly rise as more and more of the potential supply was tapped. The deficiency of 45 m.g.d. in 2010 represents only 14 percent of estimated groundwater supply, however, and should not imply severe increases in well drilling or pumping costs. Even if the high projection of increased consumptive water uses is examined, the 2010 streamflow deficiency only amounts to 27 percent of available groundwater. The problem which could occur in Region I is estuarial pollution, which we have not attempted to analyze. There is no reason to expect severe

TABLE 1

Demand and Supply Balances Projected,
Region I, Southern Maryland
(millions of gallons per day)

	1970	1980	2010
Incremental Consumptive Uses	8.5	27.8	76.5
Quality Flow Requirements	0	0	0
Total Demand	8.5	27.8	76.5
Supply (95% streamflows)	31.1	31.1	31.1
Deficiency*	0	0	45.4
Groundwater-Unused Potential	315.5	315.5	315.5

* Deficiency equals demand minus supply when this quantity is positive; it equals zero when this quantity is negative.

local problems within the Region because of its general homogeneity and widespread groundwater availability. The costs of treatment implied by the medium population projection, low and high treatment levels, are given in Table 2.

2. Region II - Western Maryland

We have defined Region II as Garrett, Allegany, Washington and Frederick Counties, stretching from the western boundary of Maryland to the continuous metropolitan areas of Baltimore and Washington, D. C. Region II is, for a number of reasons, the most complex Region in which to compare water demand and supply: It is physically heterogeneous, covering four physiographic provinces from the Appalachian Plateau to the Piedmont; it is largely drained by the Potomac River, whose watershed also extends into Pennsylvania, Virginia, and West Virginia (but a small part of the Region is drained by the Ohio River); and its freshwater streamflow is so spread among many small and medium-sized streams that regional averages are less meaningful than in most other Regions.

The Region is sparsely populated with a declining population in its western portion, where small farms, tourism, and a shrinking mining industry constitute the economic mainstays. The central portion of the Region, in Allegany County, has a combination of fruit farming and several large industrial plants producing commodities including woodpulp and paper, synthetic fibers, glass, and explosives. Railroads, while declining in employment, are still a significant economic element. The eastern end of the Region combines rich farming with small industries, and is beginning to show the effect of an expanding Washington housing market.

TABLE 2

Total Annual Costs of Alternative Regional Projections
(Sum of Storage and Treatment Costs in Maryland in Thousands of Dollars)

	1970				1980				2010			
	4 ppm		5 ppm		4 ppm		5 ppm		4 ppm		5 ppm	
	Low Treat	High Treat	Low Treat	High Treat	Low Treat	High Treat	Low Treat	High Treat	Low Treat	High Treat	Low Treat	High Treat
Region I Southern Md.	726.6	764.8	726.6	764.8	1,022.0	1,175.3	1,022.0	1,175.3	2,594.2	2,712.2	2,594.2	2,712.2
Region II Western Md.	2,519.6	2,132.8	3,225.6	2,731.8	3,554.6	3,219.5	4,130.6	3,219.5	10,419.7	9,965.0	12,486.7	9,965.0
Region III Baltimore Metropolitan	19,030.4	20,032.0	19,030.4	20,032.0	25,935.6	29,825.9	25,935.6	29,825.9	60,189.8*	62,925.7*	60,189.8*	62,925.7*
Region IV Washington Metropolitan (in Maryland)	5,160.8	5,432.4	5,160.8	5,432.4	7,156.4	8,229.9	7,156.4	8,229.9	15,290.0	16,165.8	15,290.0	16,165.8
Region V Eastern Shore	5,764.2	6,067.6	5,764.2	6,067.6	7,752.0	8,868.8	7,752.0	8,868.8	16,511.9	17,262.4	16,511.9	17,262.4
State of Maryland	33,201.6	34,429.6	33,907.6	35,028.6	45,420.6	51,319.4	45,996.6	51,319.4	105,005.6*	109,031.1*	107,072.6*	109,031.1*

* Omit costs of bringing additional Susquehanna River water to users in Region III.

The supply and demand summary in Table 3 is complex in appearance because the Region forms only a part of the watershed of the Potomac River; consequently, account must be taken of demand elements outside of the Region itself. The terms of the study exclude giving detailed attention to economic growth or demand factors in parts of the basin in Pennsylvania, West Virginia, and Virginia. Yet no estimates of Maryland potential can be made without some assumption as to the amount by which the other states of the basin will draw down available supplies. We therefore work on the basis of some rather crude assumptions to derive figures for water use outside of the State of Maryland.

For examination purposes, the Potomac watershed is divided into three parts; in addition, one small portion of Region II lies in the Ohio basin. (This includes fairly unpopulated portions of Garrett County at the extreme northwest corner of the State.) The first part of the Potomac watershed is that portion which lies north of the Potomac River. This includes areas in both Pennsylvania and Maryland. A second portion is the entire area draining into the Potomac River from the south. This lies in West Virginia and Virginia. Finally, the main stem of the Potomac River itself is considered. The remainder of this section takes these parts one by one and examines demand and supply relations.

a.) Area north of Potomac River

The increment of consumptive use in Maryland north of the Potomac River for the median level of population projection is taken from Tables in Chapter VIII. To this must be added the incremental use in the Pennsylvania portions of the drainage area north of the Potomac River, since it must

TABLE 3

Demand and Supply Balances Projected, Region II (by sections) Western Maryland (millions of gallons per day)

	1970				1980				2010			
	4 ppm		5 ppm		4 ppm		5 ppm		4 ppm		5 ppm	
	Low Treat	High Treat	Low Treat	High Treat	Low Treat	High Treat	Low Treat	High Treat	Low Treat	High Treat	Low Treat	High Treat
North of Potomac–												
Incremental Consumptive Uses												
A. Maryland	3.2	3.2	3.2	3.2	9.5	9.5	9.5	9.5	20.8	20.8	20.8	20.8
B. Pennsylvania	5.8	5.8	5.8	5.8	14.0	14.0	14.0	14.0	24.3	24.3	24.3	24.3
Quality Flow Requirements	479.0	383.0	645.0	516.0	433.0	108.0	583.0	146.0	333.0	166.0	448.0	224.0
Total Demand	488.0	391.0	654.0	525.0	456.5	131.5	606.5	169.5	378.1	201.1	493.1	269.1
Supply (95% streamflows)	258.6	258.6	258.6	258.6	258.6	258.6	258.6	258.6	258.6	258.6	258.6	258.6
Deficiency*	229.4	132.4	395.4	266.4	197.9	0	347.9	0	119.5	0	234.5	0
South of Potomac–												
Incremental Consumptive Uses (Virginia and West Virginia)	12.1	12.1	12.1	12.1	28.8	28.8	28.8	28.8	51.8	51.8	51.8	51.8
Quality Flow Requirements	414.0	331.0	557.0	446.0	374.0	96.0	503.0	126.0	270.0	135.0	363.0	181.0
Total Demand	426.1	343.1	569.1	458.1	402.8	124.8	531.8	154.8	321.8	186.8	414.8	232.8
Supply (95% streamflows)	557.8	557.8	557.8	557.8	557.8	557.8	557.8	557.8	557.8	557.8	557.8	557.8
Deficiency*	0	0	11.3	0	0	0	0	0	0	0	0	0
Potomac Mainstem–												
Incremental Consumptive Uses												
A. Maryland	3.7	3.7	3.7	3.7	9.6	9.6	9.6	9.6	20.9	20.9	20.9	20.9
B. Virginia-West Virginia	4.1	4.1	4.1	4.1	9.6	9.6	9.6	9.6	17.3	17.3	17.3	17.3
Quality Flow Requirements	746.0	570.0	1,005.0	767.0	770.0	193.0	1,037.0	259.0	926.0	463.0	1,246.0	623.0
Total Demand	753.8	577.8	1,012.8	774.8	799.2	212.2	1,056.2	278.2	964.2	501.2	1,284.2	661.2
Supply**	1,024.7	928.7	1,202.0	1,061.7	962.0	764.1	1,112.0	764.1	839.0	719.5	954.0	730.0
Deficiency*	0	0	0	0	0	0	0	0	125.2	0	330.2	0
Ohio Basin Portion–												
Incremental Consumptive Uses	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Quality Flow Requirements	9.0	7.0	12.0	10.0	8.0	2.0	11.0	3.0	5.0	3.0	7.0	3.0
Total Demand	9.1	7.1	12.1	10.1	8.1	2.1	11.1	3.1	5.1	3.1	7.1	3.1
Supply (95% streamflows)	87.7	87.7	87.7	87.7	87.7	87.7	87.7	87.7	87.7	87.7	87.7	87.7
Deficiency*	0	0	0	0	0	0	0	0	0	0	0	0

* Deficiency equals demand minus supply when this quantity is positive; it equals zero when this quantity is negative.

** Supply in the Potomac mainstem is the sum of flows into the mainstem from north and south. This quantity, for both North and South, is the larger of the following amounts: (a) The 95% streamflows minus consumptive use; (b) The quality flow requirements.

be met from the same streamflows. Table 4 gives the relations from which this estimate was derived. In 1970, for example, assuming that per capita use in the Pennsylvania portion rises at the same rate as that of the Maryland portion, the increment of consumptive use in Pennsylvania is 5.8 million gallons per day. From these two components of increased consumptive use we subtract a portion which is estimated to be withdrawn from the Potomac main stem itself rather than from the streams flowing to the main stem. This amount is estimated as slightly over 50 percent of the Maryland increment. Subtracting this figure from the sum of the two consumptive use increments leaves the amount which we project to be depleted from the streams running into the Potomac from the north (the sum of rows 1A and 1B in Table 3).

However, these figures do not include the large in-stream demand represented by the requirements for low flow dilution to maintain quality standards. Table 3, row 2, gives the medium growth projection, medium assimilation capacity waste dilution flow requirement for two levels of treatment and two quality levels. The total demand (consumptive use increment plus quality flow requirement) for the area north of the Potomac is given in row 3 of Table 3.

We turn now to a measure of supply north of the Potomac. The aggregate of the 95 percent flows in the measured streams flowing into the Potomac from the north is 258.6 million per day shown in row 4 of Table 3. Note that this figure does not account for runoff from the entire drainage area north of the Potomac. It is only runoff in measured streams, while there is an estimated additional 63.4 million gallons per day running into the main channel of the Potomac in smaller streams. Although we do not

TABLE 4

Derivation of Consumptive Use Increments, Potomac Watershed Outside of Maryland

		1960-70	1960-80	1960-2010
1.	Increment in Maryland Population[a/]	14,000	41,000	166,000
2.	Increment in Maryland Consumptive Uses[b/]	6,871,000	19,129,000	41,664,000
3.	Use Increase Per Unit Population Increase (Row 2 ÷ Row 1)	491	466	251
4.	Increment in Pennsylvania Population[c/]	11,855	30,070	96,880
5.	Increment in Pennsylvania Consumptive Uses[d/]	5,821,000	14,000,000	24,300,000
6.	Increment in Southern Drainage Population[e/]	32,925	82,380	275,480
7.	Increment in Southern Drainage Consumptive Uses[f/]	16,200	38,400	69,100

Source: As follows:

a. Table 2, Chapter II

b. Tables in Chapter VIII

c. From Corps of Engineers Report, ratio of Potomac basin Pennsylvania population to Maryland population equals .520 in 1970, .533 in 1980, 2010.

d. Row 4 times Row 3.

e. From Corps of Engineers Report, ratio of Potomac basin drainage population south of Potomac River to Maryland population, 1.370 in 1970, 1.410 in 1980, 1.449 in 2010.

f. Row 6 times Row 3.

include this in our definition of supply, it is a potential source of additional water.

Where deficiencies of supply occur - that is, where total demand exceeds supply - the amount of the deficiency is shown in row 5 of Table 3. Two aspects of these data deserve comment: first, the existence and size of deficiencies in a given year depend significantly on the policy choices made with regard to quality standards and required treatment levels. (They are also sensitive to the uncertainty involved in population forecasts and stream assimilation capacities, as will be shown later on.) Second, the projected and paradoxical decline of the deficiencies from 1970 to 2010 is the result of treatment levels which rise more rapidly than raw waste production. It is quite possible that quality problems will be more acute in the coming decades than in the more distant future, when legal and technological experience makes high treatment levels more feasible.

b.) Areas south of the Potomac River

The entire area draining into the Potomac River from the south lies outside of the State of Maryland. We therefore estimate increments in consumptive use and waste loadings - and thereby quality flow requirements in this area - by rather crude assumptions similar to those used for the Pennsylvania portion of the north side Potomac drainage. For the increment in consumptive use, we use the relation derived from Maryland consumptive use increases, and multiply the projected increase in population in Virginia and West Virginia portions of the Potomac drainage by the appropriate number of gallons per day per person. This gives a total consumptive use increment shown in Table 4. Assuming that one-fourth of this will be met from the Potomac main stem itself, the remainder will be met from streams flowing into the Potomac (this amount is shown in Table 3, row 6). Quality flow requirements are given in row 7 of Table 3, and total demand in row 8.

The supply south of the Potomac is the aggregate of flows into the Potomac at the 95 percent probability level (557.8 million gallons per day shown in row 9 of Table 3). Deficiencies are shown in row 10 of Table 3. It is necessary to know the expected flow from this region into the Potomac main stem which must be treated as joint supply for both the Maryland portion and the south shore portion. Whenever supply is less than total demand, it may be assumed that the flow into the Potomac will be the amount required for quality maintenance. Whenever supply exceeds demand, the flow into the Potomac main stem will be equal to supply minus consumptive uses.

c.) Potomac main stem

The demands to be met from the Potomac main stem itself are those which have been subtracted previously from demand figures north and south of the Potomac; that is, those increased demands north and south of the Potomac which we estimated would be served from the Potomac main stem itself. These are shown in rows 11A and 11B of Table 3. In addition to this, there is a flow requirement for quality control, once again based on the amounts of waste charged to the main stem from north and south. This requirement is given in row 12 of Table 3 and total demand is in row 13.

The supply in the Potomac main stem consists of those volumes of water delivered to it from the drainage to north and south. As discussed above, these volumes will either be quality flow requirements (in the cases where deficiencies exist) or 95 percent flows depleted by consumptive uses (in the cases where there are not deficiencies). The total supply in the main stem is given in row 14 of Table 3; deficiencies are shown in row 15. For the main stem at this reach well above Washington, D. C., deficiencies are projected only in 2010, and even these occur only under low treatment level assumptions.

It is important to keep in mind, however, that the Potomac is virtually the only source of water for the National Capital area, whose demands are very rapidly increasing. The analysis of demand and supply in Region II is consequently incomplete until deficiencies in Region IV have been calculated. We therefore return to this point later in the Chapter.

d.) Ohio Basin portion of Region

The 1960 population in the Ohio Basin portion of Maryland in Garrett County was approximately 10,000. Little population or employment increase is projected for this area, and the increments in consumptive use will be very small, probably in terms of a few thousand gallons per day (see row 16, Table 3). Table 3 also shows estimated quality flow requirements in row 17, total demand in row 18, and the 95 percent flows (supply) in row 19. As can be seen from row 20, it is not expected that consumptive uses plus quality flows will exceed supply even by 2010.

e.) Overall Region II demand and supply

The generalized balances given in Table 3 show that large deficiencies occur under a combination of low treatment levels and high quality standards. The form of presentation in this table also conceals local shortages which exist in parts of the Region even today. The costs involved in alternative outcomes are given in Table 2.

3. Region III - Baltimore Metropolitan

This Region consists of Baltimore City and Baltimore, Anne Arundel, Carroll, Harford, and Howard Counties; it differs from the Census - defined Standard Metropolitan Statistical Area only by the inclusion in our study of Harford County, which was not part of the SMSA in 1960. The Region includes an extensive rural area stretching to the Pennsylvania border in the north, and to the tobacco farms of Southern Maryland on the south. It has a long shoreline on the brackish waters of the Chesapeake Bay on the east.

Most of the heavy industry in the State is in this Region, and its share of the State's manufacturing employment is projected to drop only slightly by 2010. Population density is now over 800 per square mile, with a projected increase to 1770 per square mile by 2010. Consequently, the uses are primarily municipal and industrial, and projected waste production is high.

Table 5 shows demand-supply comparisons for the Baltimore Metropolitan Region. The first five rows show the components of demand, total demand, supply (available 95 percent of time), and deficiencies where demand exceeds supply. In contrast to Western Maryland (Region II), deficiencies appear only in 2010, and are chiefly due to increases in consumptive use. The deficiency expected with low treatment levels and high quality standards is only 16 percent higher than that associated with high treatment and lower quality standards.

There are two reasons for these characteristics: First, the relative and absolute growth of population and employment is much higher in Region III than in Region II, generating high consumptive use demands. Second,

TABLE 5
Demand and Supply Balances Projected
Region III, Baltimore Metropolitan Area
(millions of gallons per day)

	1970				1980				2010			
	4 ppm		5 ppm		4 ppm		5 ppm		4 ppm		5 ppm	
	Low Treat	High Treat	Low Treat	High Treat	Low Treat	High Treat	Low Treat	High Treat	Low Treat	High Treat	Low Treat	High Treat
Incremental Consumptive Uses	99.6	99.6	99.6	99.6	283.8	283.8	283.8	283.8	982.2	982.2	982.2	982.2
Quality Flow Requirements	85.0	68.0	114.0	92.0	87.0	22.0	117.0	29.0	103.0	51.0	138.0	69.0
Total Demand	184.6	167.6	213.6	191.6	370.8	305.8	400.8	312.8	1,085.2	1,033.2	1,120.2	1,051.2
Supply (95% flows)	475.9	475.9	475.9	475.9	475.9	475.9	475.9	475.9	475.9	475.9	475.9	475.9
Deficiency*	0	0	0	0	0	0	0	0	609.3	557.3	644.3	575.3
Susquehanna Flow to Bay (95%)	3,262	3,262	3,262	3,262	3,262	3,262	3,262	3,262	3,262	3,262	3,262	3,262
Unused Groundwater Supply	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0

* Deficiency equals demand minus supply when this quantity is positive; it equals zero when this quantity is negative.

we have assumed that a very low proportion of all wastes produced in Region III will be discharged, after treatment, to fresh water streams (See Table VII - 7). If future events contradict this assumption, the deficiencies in Region III would rise very substantially. (See costs in Table 2.)

The sixth row in Table 5 shows the estimated flow available 95 percent of the time in the Susquehanna River as it flows into the Chesapeake Bay between Harford and Cecil Counties. The City of Baltimore has nearly completed an aqueduct which will carry 250 m.g.d. from the Susquehanna. Whether additional amounts will be available in the future, up to the quantities of over 600 m.g.d. shown as deficiencies in Table II-5, depends mainly upon upstream development in the Susquehanna Basin, now under study by a large inter-agency group coordinated by the U. S. Army Corps of Engineers. It would appear to be extremely important to the Baltimore Region to make its future needs known to this group.

4. Region IV - Washington Metropolitan Region in Maryland

Region IV consists of only two counties, Prince George's and Montgomery, which are the Maryland part of the fast-growing Washington Metropolitan Area. Most of Montgomery County is on the piedmont, while Prince George's is on the coastal plain. The population of the Region is projected to grow by 2010 by 230 percent and reach a density of well over 2,000 per square mile. While some industrial growth is also projected, the principle increase in water use is expected to be in municipal systems. Most discharges of treated wastes are to the Potomac estuary, which we have treated as brackish water at and below the District of Columbia.

Table 6 records the demand-supply comparisons for Region IV. Even with substantial increases in consumptive uses, only a small deficiency is

TABLE 6

Demand and Supply Balances Projected, Region IV, Maryland part of Washington, D. C. Metropolitan Area

(millions of gallons per day)

	1970				1980				2010			
	4 ppm		5 ppm		4 ppm		5 ppm		4 ppm		5 ppm	
	Low Treat	High Treat	Low Treat	High Treat	Low Treat	High Treat	Low Treat	High Treat	Low Treat	High Treat	Low Treat	High Treat
Incremental Consumptive Use												
A. Maryland	80.0	80.0	80.0	80.0	169.9	169.9	169.9	169.9	534.3	534.3	534.3	534.3
B. District of Columbia	22.0	22.0	22.0	22.0	34.2	34.2	34.2	34.2	79.9	79.9	79.9	79.9
C. Virginia	49.1	49.1	49.1	49.1	103.0	103.0	103.0	103.0	289.9	289.9	289.9	289.9
Quality Flow Requirements (Maryland)	64.0	51.0	86.0	69.0	67.0	17.0	90.0	23.0	64.0	32.0	86.0	43.0
Total Demand	215.1	202.1	237.1	220.1	374.1	324.1	397.1	330.1	968.1	936.1	990.1	947.1
Supply (components)												
A. Streams in Region	79.4	79.4	79.4	79.4	79.4	79.4	79.4	79.4	79.4	79.4	79.4	79.4
B. Virginia Streams	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0
C. Potomac Mainstem	1,016.9	920.9	1,194.2	1,053.9	942.8	744.9	1,093.8	744.9	926.0	681.3	915.8	691.8
Total Supply	1,161.3	1,065.3	1,338.6	1,198.3	1,087.2	889.3	1,238.2	889.3	1,070.4	825.7	1,060.2	836.2
Deficiency*	0	0	0	0	0	0	0	0	0	110.4	0	110.9
Groundwater Supply	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0

* Deficiency equals demand minus supply when this quantity is positive; it equals zero when this quantity is negative.

shown by 2010. The major item left out of these calculations is the maintenance of quality in the Potomac estuary, which was estimated by the U. S. Public Health Service to require flows ranging from 1900 to 2400 m.g.d. This item alone, if borne out by future studies, would create large deficiencies which could only be met by increased flows from Region II, Western Maryland. The costs involved under alternative programs are given in Table 2.

5. Region V - Eastern Shore

This Region consists of nine counties, from Cecil at the head of the Chesapeake Bay to Worcester, facing the Atlantic Ocean. Although the Region accounts for 34 percent of Maryland's area, in 1960 it contained only 8 percent of the State's population. Our projections indicate a slight decline in the Eastern Shore's *proportion* of Maryland population by 2010, even though a steady increase in absolute numbers is expected.

Region V lies almost entirely on the coastal plain, and is underlain with substantial groundwater resources. The economy depends heavily upon agriculture and fisheries (and the processing of these products), and upon tourism along the Atlantic Coast. No point in this Region is far from either the Bay or its estuaries, or from the Ocean, and, consequently, virtually all treated wastes are projected to be discharged to salt or brackish water. Since the watersheds from which Region V supply is to be drawn lie partly in Pennsylvania and Delaware, a crude estimate of incremental consumptive uses in these areas is also made.

Table 7 records demand-supply comparisons for Region V. As with Region I, the table is simple - no quality flows are projected, because no wastes are to be discharged to freshwater streams. In brief, a deficiency is projected only for 2010, and the amount is very small relative to the

TABLE 7

Demand and Supply Balances Projected, Region V, Eastern Shore

(millions of gallons per day)

	1970	1980	2010
Incremental Consumptive Uses			
A. Maryland	40.5	112.7	269.7
B. Delaware, Pennsylvania	20.2	45.1	80.9
Total Demand	60.7	157.8	350.6
Supply (95% streamflows)	314.8	314.8	314.8
Deficiency*	0	0	35.8
Groundwater-Unused Potential	933.5	933.5	933.5

* Deficiency equals demand minus supply when this quantity is positive; it equals zero when this quantity is negative.

untapped groundwater supply - it amounts to only about 4 percent of groundwater reserves, and should not, therefore, imply increased costs in obtaining groundwater. Costs of alternatives appear in Table 2.

D. Summary and supplemental considerations

The conclusions drawn for each of the five Regions will be discussed, and recommendations made, in Chapter XI. However, it is essential to keep in view the context from which these conclusions are drawn, including especially a number of considerations which did not enter into the calculations presented.

Two alternative ways of bringing demand and supply into balance within each Region have been examined: 1.) Demand may be cut down by reducing quality flow requirements (either by higher treatment levels or less stringent quality standards), or 2.) supply, on a dependable basis, may be increased for certain regions by building storage to regulate stream flow. We have also indicated probable groundwater availability, but have not conducted detailed studies of the cost of obtaining additional amounts of groundwater.

There are, however, other possible ways of balancing demand and supply of water. Demand might be lowered through the separate decisions of household and industrial water-users to substitute other commodities or productive factors for water in a myriad of uses; public policy could enter in either in the form of use regulations (as are now used in temporary shortages) or in a pricing policy which charged users higher rates than at present. Although we have attempted estimates of price elasticity of water by domestic users and industries, existing data are inadequate to derive meaningful results. We can only indicate this very real alternative.

Another method for reducing demand for water is to transport treated or untreated wastes to the open ocean, instead of using streams as waste carriers and purifiers. There are now estimates of pipeline costs[4] which could be used, but in the absence of investigation as to the possible effects on the ocean itself, we have not examined this possibility in detail.

On the supply side, water could also be transported into the State, or among Regions, by pipeline or canal. Again, recent investigations in the Johns Hopkins University Sanitary Engineering Department provide some cost data.[4] Supply might also be increased by desalinization of salt or brackish water; a considerable amount of research in this field is underway, but expert opinion is by no means unanimous on the costs to be expected.

In addition to the alternatives discussed in the preceeding paragraphs, there are other water development issues which have not been treated at length in this report. One such problem, mentioned briefly in Chapter VII, is the possibility of severe pollution of the brackish estuaries bordering the Chesapeake Bay, or of the Bay itself. These waters are complex ecological systems involving plant and animal life, organic and inorganic chemical constituents, seasonal changes of streamflow and temperature, and increasingly intensive uses by man.

The Chesapeake Bay and its estuaries and tributaries are in many ways the most important and unique of Maryland's natural resources. The tidewater counties of Maryland comprise sixteen of the twenty-three counties, and in 1960 accounted for forty-seven percent of the total population in the State. It seems quite clear that the cleanliness of these waters is of such significance to the entire State that very effective enforcement of pollution control regulations are essential to the economic future of the State.

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[4] The Future Uses of Saline and Fresh Water Resources of the United States, Seminar Report of the Sanitary Engineering Department, Johns Hopkins University, June, 1964.

It has also been mentioned previously that the organic BOD pollution with which our analysis deals is only one of many pollutants of water. In this report there has been no attempt to define solutions, or estimate their costs, to such pollution problems as sediments and silt, acid mine wastes, exotic organic chemicals (drugs, insecticides, detergents, etc.) or possible effects of nuclear power generation or temperature increases. These are all real or potential dangers in one part of Maryland or another, and their importance should not be minimized.

Still another issue which is certain to be of increasing concern in the State is the distribution of costs and benefits arising from waste disposal and treatment. The economic and social costs resulting from wastes which pollute a stream are often borne, not by the polluter, but by other "downstream" users of the water. Similarly, benefits from the treatment of wastes may accrue largely to those "downstream" who receive purer water. This issue has recently received attention in professional literature[5], and both justifies and complicates the regulating actions of local, State, and Federal governments. It is much too large a matter to have been included in this report.

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[5] E.G. Allen V. Kneese, The Economics of Regional Water Quality Management, Johns Hopkins Press, 1964.

Finally, water uses, supplies, and policies have been treated as if they were dependent on, but exerted no influence upon regional population and economic growth. Certainly, this is not the case. The availability and quality of water at the necessary time and place, and the cost of making such water available are of great and growing importance in the location decisions of industries and the residential and recreational choices of the population. There is an intimate dependence of these factors upon one another, which we have ignored only in order to bring one problem to manageable proportions for this study.

CHAPTER XI

SUMMARY AND RECOMMENDATIONS

A. Introduction

This Chapter incorporates the conclusions of the entire study and discusses in detail those water resource development policies which the study indicates to be desirable.

The outline of the Chapter is as follows: Section B presents the broad water resource picture that emerges for each of the five Regions, and for the State as a whole. The major conclusions of the study, pertaining to the kinds and amounts of water resource developments desirable in each of the five Regions, are presented in that section. In Section C the results of the present study are compared with those of the Corps of Engineers' Potomac River Basin Report. Exact comparisons are not possible, since the two studies consider overlapping, but not identical, areas. Nevertheless, it is important to make rough comparisons between their conclusions and those of this report, and to ascertain the reasons for major differences between them. Section D presents a number of additional recommendations related to specific water-using sectors. Finally, Section E presents a number of topics on which further research and data collection are needed.

B. Water resource data by Region

Briefly, this study indicates that for two Regions, the Eastern Shore (Region V) and three Southern Maryland counties (Region I), anticipated consumptive water uses and quality maintenance should not constitute a serious problem even by 2010, although increased use of groundwater in both areas will be required. In the Baltimore Metropolitan Region (Region III), severe deficiencies may be expected by 2010, due mainly to anticipated sharp increases in consumptive uses; however, these deficiencies can be met adequately by flows of the Susquehanna River if upstream users in that basin do not pre-empt more than some 70 percent of flows.

Western Maryland (Region II) may face rather small deficiencies even in the near future, although the existence and extent of these deficiencies will be determined largely by particular combinations of policies and conditions. Relatively small amounts of storage could meet Region-wide needs, but the topography, drainage, and population distribution of the area might well require more storage than the minimum suggested. The portion of Maryland adjacent to the District of Columbia (Region IV) is not itself projected to face shortages, but since requirements for the entire Washington Metropolitan area must also be met nearly entirely from Potomac flows, small deficiencies are projected.

The critical role of estuarial quality in a balanced evaluation of the State's water prospects cannot be emphasized too strongly. For example, the U.S. Public Health Service estimates of flows required in the Potomac estuary at Washington range from 1,900 to 2,400 m.g.d. - enough to cause very large deficiencies in Region IV which could only be met by large increases in storage in the upper Potomac Basin, either in Region II of Maryland, or in Virginia, West Virginia, and Pennsylvania. In addition, our projections imply waste discharges to the Chesapeake Bay and its estuaries from Regions I, III, and V, which may well spell serious pollution dangers to waters which are of vital importance to the State economically and aesthetically.

This report's broad recommendations will therefore have to be reevaluated as better information concerning estuarial pollution and its prevention becomes available. With this caveat, the public actions which would be consistent with this study's solutions are:

1. The requirement of considerably higher average levels of waste treatment than now prevail. Under what we consider to be the most likely future conditions, it appears that the overall least-cost method of meeting needs would require average treatment levels of 80 percent in 1970 and 95 percent in 1980 and 2010. If these levels are deemed unachievable, at least for the earlier decades, levels of 75 percent in 1970, 80 percent in 1980, and 90 percent in 2010 would be workable (though more expensive) compromises. Although this measure may not be of pressing importance in Regions I and V where wastes after treatment are assumed to be discharged to salt or brackish waters, the dangers of estuary pollution, and the difficulty in administration of a policy which differentiates among Regions, make a statewide treatment requirement preferable.

2. The construction of from 60,000 to 440,000 acre feet of reservoir capacity in Western Maryland or the Potomac watershed portion of Pennsylvania, primarily to provide low flow augmentation in the streams which flow into the Potomac from the north. Closer examination (such as that undertaken in the Corps of Engineers study) might well reveal a somewhat larger storage requirement in order to meet needs at specific points within the Region, especially in the Cumberland area of Western Maryland.[1]

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[1] Note that no analysis is made of flood control requirements which are critical in certain parts of Western Maryland.

3. It would be desirable for the Baltimore Metropolitan Region to have assurance of as much as 750 million gallons per day from the Susquehanna River over and above the 250 million gallons per day to which rights now exist and for which an aqueduct has been constructed.

C. Comparison with Corps of Engineers report

Inevitably, the conclusions in this study must be compared with those of the Corps of Engineers in their Potomac River Basin Report. In this section certain comparisons are made, and the lack of basis for other comparisons is pointed out. On the whole, the findings in this study, where comparable, are consistent with those of the Corps of Engineers' report, although differing in some details and in emphasis.

One comparison by which this report suffers is the choice of overall study area; the State of Maryland is bounded by lines which are recognized neither by water nor by economic development forces. Some of the cumbersome analysis, especially of Western Maryland, and a great deal of the dependence upon crude assumptions as to water use outside of the State of Maryland would be unnecessary in a study whose scope extended over complete river systems. The Potomac River Basin Report _does_ cover all of the Potomac watershed, but only that watershed, and, consequently, deals with only about 35 percent of Maryland's land area.[2] It is thus only for Regions II and IV of our study that parallel conclusions are drawn, and even for these two Regions, the geographical basis for comparison is not perfect.

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[2] Conversely, Maryland accounts for only some 25 percent of the Potomac watershed.

The assumptions underlying analysis are similar, though not identical. Population and employment projections used in this study are somewhat higher than those of the Corps of Engineers' study for the Washington area, but lower for Western Maryland - although exact comparisons are made impossible by different area delineations. As noted in Chapter VII, the waste assimilation capacities used by the Public Health Service in the Potomac River Basin Report are mostly lower than our low assumptions, and far lower than our medium and high assumptions. The quality standard behind the major results in both studies is 5 p.p.m. dissolved oxygen. Because this study defines return flows to the Potomac River at and below Washington as consumption, our projected consumptive uses for the Washington area are considerably higher than those in the Potomac River Basin Report. Still another point of difference between the two studies is the risk level implied in the concept of dependable flow or supply. While most of our analysis has considered the flow equalled or exceeded 95 percent of the time, the Corps of Engineers' study uses the smaller amount to which flows decline over a seven day average with 10-year recurrence. The latter concept yields amounts of roughly one-half of those used in this study; the effect is equivalent to reducing the supply estimates in Chapter IX by one-half or more. It is therefore to be expected that more shortages will be projected in the Corps of Engineers' study, and that they will be more severe.

On one major recommendation the two reports are apparently in full agreement: waste treatment levels substantially higher than those now in effect are an essential part of optimum water development. Compare our statement on page 257 of this Chapter with the following from the Potomac River Basin Report: "The analyses of the economics and practicability of the solutions considered for water quality control showed that any plan of development must include a high level of waste treatment as a prerequisite. A positive program of waste collection and provision of maximum practicable and economical treatment of these wastes before discharge into the streams of the Potomac River drainage system is mandatory."[3]

The specific treatment levels assumed in the calculation of quality maintenance flows do differ somewhat between the two studies, however; Table 1 shows the percentages assumed in both studies. The Potomac River Basin Report's levels for the Washington Area are comparable to our low treatment levels, while its assumptions for the rest of the Basin fall slightly below our low levels. These differences mean that the Potomac study relies somewhat more on flow augmentation than this report, possibly on the basis of well-founded doubts as to the administrative feasibility of requiring higher waste treatment levels.

TABLE 1

Waste Treatment Levels Assumed in the Maryland Study and the Potomac River Basin Study

	1970	1980	1985	2010
Potomac Study -				
A. Washington Area			85%	90%
B. Rest of Basin			80%	85%
Maryland Study -				
A. Low treatment	75%	80%		90%
B. High treatment	80%	95%	(95%)	95%

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[3] Potomac River Basin Report, U.S. Army Corps of Engineers, Volume I, p. 22.

A comparison of recommended reservoir storage construction is also quite difficult. The Potomac River Basin Report's recommendations call for 490,000 acre feet of storage in major reservoirs in Maryland, Pennsylvania, and the upper Potomac main stem (the Seneca dam is excluded from this figure). In addition, small headwater storage in the Maryland and Pennsylvania part of the Potomac Basin adds another 268,000 acre feet of storage for a total of 758,000 acre feet. The annual costs of this amount of storage are estimated at approximately $6,654,000.

By comparison, the storage requirements indicated for Region II in this study (derived from Table 3, Chapter X) range from 60,000 acre feet to 440,000 acre feet; the cost is estimated from $750,000 to $3,000,000 annually. One must judge whether the following factors are sufficient to account for this sizeable difference:

1. This report's higher treatment levels mean smaller waste discharges, and therefore require less streamflow.

2. The lower waste assimilation capacities used by the Potomac River Basin Report also lead to larger streamflow requirements.

3. This study did not include surcharge storage requirements which are included in the Potomac River Basin Report.

4. Our study's analysis of a large Region as a unit has undoubtedly blurred over local imbalances between demand and supply within the Region. This is particularly the case for the area around Cumberland for which North Branch projects have been proposed by the Potomac River Basin Report, and for the small headwater impoundments proposed on several streams.

5. The Potomac River Basin Report projects greater growth of population and industry in Western Maryland than this study.

6. Finally, the base stream flow upon which increases are to be made by storage is smaller in the Potomac River Basin study than in our study.

The largest and most controversial unit in the Potomac study's recommendations is the large dam (1,010,000 acre feet) on the main stem of the Potomac River at Seneca. The results of our study indicate that need for the Seneca dam (or some similar amount of storage in the upper Potomac Basin) depends primarily on streamflow requirements for Potomac estuary quality maintenance. While a large proportion (40 percent) of the Seneca costs are allocated to quality control in the Potomac River Basin Report, another 13 percent of costs are charged against water supply (the remainder of costs are for flood control and recreation).

D. Additional recommendations

The implications of this study for the overall water resource development of the State has been presented in Section C. In this section we present several additional recommendations related to specific water uses.

1. Waste discharges and water quality

Attention of those concerned with water development in the industrialized urban sections of the country has increasingly focussed upon the problem of maintaining water quality. This study has shown the overwhelming importance of the use of water for waste assimilation in portions of Maryland, even when relatively high rates of waste treatment are projected.

The construction of storage to increase dependable low flows for waste assimilation is a task which must be undertaken by government at some level - it does not produce a saleable product, it requires tools such as eminent domain, and its planning should be integrated with other basin-wide objectives. The treatment of wastes, however, will be undertaken partly by private firms and partly by a large number of relatively small municipal units.

Consequently those are major issues of administration and enforcement raised by the prospect of a need to raise the overall level of waste treatment in a Region or in the State. While we are clearly not in a position to make specific recommendations on these issues, we do urge the Department of Water Resources and other state officials to consider and evaluate a wide range of possible approaches, including the following:

a. The levying of fees against persons, municipalities, or firms for the privilege of discharging wastes into streams.[4] These fees might be graduated according to waste amount, content, and timing, and possibly even according to the assimilative capacity of the particular stream system involved. The purpose of a system of fees would be to provide incentives for waste dischargers to treat wastes (or to use processes which generate less waste, produce by-products, etc.) and revenues raised might be used directly for financing flow augmentation measures.

b. The tightening of legal requirements for treatment and more financial support for their day-to-day enforcement. It would be necessary either to do a great deal more sampling of waste discharges, or to require full and accurate reporting of discharges by firms and municipalities.

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[4] Though referring here to streams, much of the discussion might also apply to estuarial waters or lakes.

c. The promotion of cooperative arrangements by waste dischargers in particular river systems to analyze the actual effect of each one's waste discharges upon water quality. Such group arrangements could achieve overall minimum cost programs of quality control, with costs being shared equitably among members of the group. Industry A's untreated wastes may not cause water quality to fall below a standard, but may cause Industry B (downstream) to undertake high levels of treatment of its wastes. Under a cooperative arrangement, Industry B would receive some subsidization for waste treatment.[5]

2. Irrigation withdrawals in the Piedmont area

It is suggested that where reservoirs are built to maintain flows in the Piedmont counties, for municipal supplies, power, dilution, recreation, etc., consideration be given to a system of regulation which would allow farmers (or other users) to take water without charge from streams when they are in flood flow and reservoirs are full; and which would charge a fixed rate for taking water at times when the reservoir is not full and flows are low. This would apply to users within a service area extending both above and below the reservoir. The rate should be based on the portion of the annual cost of storage allocated to withdrawal uses. Such a system would provide an incentive to use otherwise wasted waters during high flows and to reduce the load on low flows, and would make it possible for farmers to compete in the market with other users of water when it is in short supply.

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[5] The most highly developed arrangement of this sort are the Genossenschafter of the Ruhr area in Germany. For discussion of these see Allen V. Kneese, Economics of Regional Water Quality Management, The Johns Hopkins University Press, 1964, Chapter 7.

Clearly, considerable legislation would be necessary to institute this sort of policy. Note that this proposal differs from that of the Delaware River Basin Survey which would provide irrigation water by pipes along streams at a constant price based on a partial share of storage costs.

3. Recreation

In Chapter VI it was concluded that the number of visits per capita to intermediate recreational facilities will grow from about one in 1960 to ten in 2010. This recreational "explosion" will require vast increases in acreage devoted to intermediate recreation if severe overcrowding is to be avoided. In 1961, almost all intermediate recreation took place in the 18,000 acres of state parks. By 2010, the required acreage for intermediate recreation will be about 20 times that figure. Even if the entire Corps of Engineers Potomac plan is carried out by that time, vast increases in acreage will be required. Although substantial additions have been made to Maryland's state parks in recent years, visits are increasing faster than acreage. We recommend that serious study be made of the possibility of developing some of Maryland's state forests for more intensive recreational use.

The relationship between intermediate recreation and the quality of the water in nearby lakes and streams needs further study. It is clear that recreational and aesthetic requirements will necessitate much higher treatment levels for industrial wastes in the coming decades than now prevail in the State. Further study should be undertaken of the precise relationship between various kinds of recreational activities and water quality. Study should also be undertaken to discover the best ways of achieving higher treatment levels of industrial wastes. The prevailing method of issuing permits is very imperfect and considerable interest has been shown recently in a number of schemes for metering and taxing the discharge of industrial wastes.

E. Further research and data collection

Inevitably, a study of this sort brings to light many areas where further research and data are needed. In almost every chapter in this report, questions have arisen which cannot be adequately answered with existing data and techniques. Answers can be found to most of these questions with additional research and careful collection of data. The identification of areas for further study is a major purpose of this project. The purpose of this section is to bring together the most important topics for further research encountered in this study.

1. It should already be evident that we consider the comprehensive study of the ecology and quality problems of estuarial waters to be an urgent need in the State of Maryland. To be of greatest use in conjunction with our study, estuarial quality research should identify the role played by the volume of freshwater flows into an estuary, as well as the maximum expected waste loads which can be assimilated by estuaries.

2. Although much more is known about the assimilative capacity of freshwater streams, further information is needed, derived both from more extensive and frequent physical testing and from theoretical inquiries such as the computer model developed here or the work of the U.S. Public Health Service in the Delaware Basin.

3. One of the most severe data gaps today is the lack of reliable, complete, and continuous information on waste outfalls. A program to collect such data should include quantity of several polluting substances, timing of

discharges, temperature, location, and enough related information to make possible the investigation of waste discharges as functions of industrial activity and population characteristics.

4. Since groundwater is the major source of future water supply in the coastal plain areas of Maryland, more data on dependable quantities, quality, and costs incurred in drilling, pumping, and storing should be collected and analyzed.

5. Further State studies in Maryland should be undertaken under cooperative arrangements with the states of Pennsylvania, Virginia, West Virginia and Delaware, and with the District of Columbia so that basin-wide analysis can be made. In addition it is not too soon to begin investigating administrative and institutional means of cooperating with these states, for example to set waste treatment requirements or regulate streamflows.

Appendix A

1963 Maryland Industrial Water Use Survey Data

During 1963, the Maryland Planning Department undertook an extensive survey of industrial water use in Maryland in cooperation with the Chesapeake Bay-Susquehanna River Basins Project of the U.S. Public Health Service. We are indebted to these organizations for making their preliminary data available to us. Although these data were received too late to incorporate in the basic projections in the text of this chapter, we feel that it is important to make tabulations of them available for users of this Report.

The Survey was intended to cover approximately the same group of industrial water users that was included in the 1959 Census of Industrial Water Use, i.e., those industrial establishments using more than about 20 million gallons of water per year. (Small variations in this cut-off point will have a substantial effect on the employment data obtained, but little effect on the water data obtained, since water use is heavily concentrated among the largest water-using establishments.)

The 1963 survey collected much more detailed data, especially relating to the discharge of effluent, than was published by the Census. However, the response to the 1963 questionnaire was much more complete in answer to the questions on intake and employment than to most other questions. We have, therefore, restricted our tabulations to the intake and employment data, since these allow comparisons with the Census.

Table A1 presents the comparison between the Census and Survey data. However, several remarks are necessary before discussing the data in detail. First, "N.A." under the Census columns indicates that the Census did not publish the figure because of their disclosure rules. Second, four years elapsed between the two surveys. Since most of the heavy water-using industries grew rapidly during that period, the 1963 Survey intake and, less so, employment figures, should be larger than the corresponding Census figures. Third, the 1963 questionnaire employed a faulty classification between brackish and non-brackish sources. Two of the sources on the questionnaire were "river" and "brackish". However, these are not mutually exclusive and many firms marked "river", even though withdrawals were from estuaries. In the data presented in Table A1, we have recalssified some withdrawals from fresh to brackish on the basis of information concerning the location of withdrawals. (The data for total withdrawals are not affected by this reclassification.) Fourth, figures for intake per employee in the 1963 Survey are not ratios of figures in the total intake column to figures in the employees column. Some firms provided data on intake but not employment. Such data are included in the intake column. The intake per employee column, however, was computed from the intakes of only those firms that also provided employment figures.

On the whole, there is remarkable consistency between the two surveys. In most industries for which data from both surveys are available, total withdrawals in the 1963 Survey exceed those from the Census by amounts that represent plausible estimates of growth between 1959 and 1963. The major exception to this is industry (28), Chemicals. There is a strong presumption that the 1963 Survey missed one or more major water users in this industry. Less important discrepancies occur in the Rubber industry (30) and Fabricated Metals (34). The total withdrawal figures indicate a rapid, but not impossible, rate of growth in Maryland industrial water use between 1959 and 1963. The Survey figure of 970 m.g.d. for 1963 is 28 percent greater than the Census

TABLE A1

Industrial Water Intake and Intake Per Employee, Maryland, 1959, 1963

	Intake (000 g.p.d.)						Employees (000)		Intake/Emp. g.p.d.	
	BRACKISH		FRESH		TOTAL					
Industry	Census 1959	Survey 1963	Census 1959	Survey 1963	Census 1959	Survey 1963	Census 1959	Survey 1963	Census 1959	Survey 1963
20 Food	16,438	24,058	21,918	23,506	35,616	47,564	15	16.0	2,374	2,978
21 Tobacco	NA	-	NA	-	NA	-	NA	-	NA	-
22 Textiles	NA	-	NA	43,058	NA	43,058	NA	3.6	NA	11,969
23 Apparel	NA	-	NA	59	NA	59	NA	0.9	NA	66
24 Lumber	NA	-	NA	73	NA	73	NA	0.6	NA	133
25 Furniture	NA	-	NA	643	NA	643	NA	1.4	NA	461
26 Paper	NA	-	NA	6,068	NA	6,068	NA	2.1	NA	2,428
27 Printing	NA	-	NA	150	NA	150	NA	3.1	NA	41
28 Chemicals	49,315	12,300	57,534	49,709	104,110	62,009	8	4.9	13,014	10,762
29 Petroleum	NA	12,008	NA	1,167	NA	13,175	NA	0.6	NA	21,500
30 Rubber	-	-	13,698	8,521	13,698	8,521	7	9.1	1,957	937
31 Leather	NA	-	NA	315	NA	315	NA	0.7	NA	466
32 Stone, clay, glass	-	-	10,959	18,511	10,959	18,511	5	4.0	2,192	1,886
33 Primary metals	397,256	622,933	82,191	122,965	476,708	745,908	32	31.1	14,897	23,988
34 Fab. metals	-	-	2,740	2,210	2,740	2,210	4	4.0	685	483
35 Non-elec. machinery	NA	-	NA	4,372	NA	4,372	NA	14.9	NA	260
36 Elec. machinery	-	-	2,740	4,474	2,740	4,474	8	15.9	342	266
37 Trans. eqmt.	2,740	5,821	5,479	4,060	8,219	9,881	36	7.1	228	325
38 Instruments	NA	-	NA	-	NA	-	NA	-	NA	-
39 Miscellaneous	NA	-	NA	3,028	NA	3,028	NA	5.0	NA	601
Total	498,625	677,120	254,792	292,889	758,899	970,006	128	124.9	5,929	7,529

Sources: Unpublished Maryland Survey, Census of Manufactures, 1959.

Notes: NA - not available; dash (-) no intake reported.

figure of 293 m.g.d. for 1959. By way of comparison, the Census figures for industrial water withdrawals in Maryland indicate a 5 percent growth from 1954 to 1959.

Although the two surveys indicate a rapid growth of industrial withdrawals, this growth is much more heavily concentrated in brackish than in fresh water withdrawals. The two surveys indicate that, between 1959 and 1963, brackish withdrawals in Maryland increased by 36 percent, whereas fresh water withdrawals increased by only 15 percent.

Comparison between the Survey estimate of total fresh water industrial withdrawals for 1963 in Table A1 and this Report's estimate for 1960 given in Table 6 indicates that our figure is slightly higher - 306 m.g.d. as compared with 293 m.g.d. This difference is mainly accounted for by the omission from the 1963 data of a large fresh water-using firm in the Pulp and Paper industry (26). There are other substandard discrepancies between Tables 6 and A1 for several industries, but the totals are remarkably consistent.

The intake per employee data in Table A1 are also broadly consistent. The estimated rise in the total from 5,929 g.p.d. to 7,529 g.p.d. probably is somewhat too rapid, but is not impossible. There is a major discrepancy between the Census and Survey estimates only in the Rubber industry (30).

Appendix B

A Computer Model for Stream Quality Testing[1]

As one part of the Maryland Water Supply and Requirements Study being conducted at the Johns Hopkins University, we have constructed a computer model for stream flow and water quality analysis. This model has been used with data for the Monacacy River in Maryland to study the effects of increased pollution loads, alternative spacing of pollution outfalls, alternative design flows and water quality standards, and eventually to help to identify minimum cost combinations of sewage treatment levels and storage for low flow abatement.

In its present form the model operates with 4-hour time periods. Output values are given for points on the stream which may be intakes, outfalls, tributary confluences, or arbitrarily selected points. For each such point for each time period outputs are: volume of flows, withdrawals, and discharges in cubic feet; organic pollution load in p.p.m. of B.O.D., and dissolved oxygen content in p.p.m. In addition print-outs indicate the following: points where violations of quality standards initially occur; treatment required at each waste outfall to correct violations (both with and without flow augmentation); total annual cost of treatment and of storage for the entire stream after quality standards have been met at all points.

It is intended that alternative input values for stream flows can be either steady levels, historic sequences, or synthetic hydrologies with random components and serial correlation. Similarly, although at the outset

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1. Much of the programming and testing of this model was done by Jacquelyne Bullock and Ethan T. Smith.

polluting discharges and consumptive uses will be single valued, further development could incorporate stochastic variation in these variables as well.

Other input values include values for the deoxygenation and reaeration constants in the oxygen sag equation. These are specified externally and the effect of changes in their assumed values can be studied.

Very briefly, the operation of the model is as follows: For the first time period, flows are entered for "initial stations" (these are defined as the uppermost station in the main branch and in each tributary). These flows are either read in as data or computed from a hydrology subprogram. Similarly, pollution loads and oxygen content are entered for initial stations. For all downstream stations the program gives no output for time period 1.

In time period 2, new flow, pollution, and oxygen values are read in (or computed) for initial stations. For all downstream stations for which the distance below the nearest initial station divided by velocity equals 1, the program then computes flow as a function of the upstream initial station flow plus inflow (main channel watershed runoff, tributary inflows, and waste water outfalls) minus losses (water intakes). The program next computes for these downstream stations the pollution load as a function of the upstream pollution load altered by stream purification between the two stations plus new pollution added at that point. Dissolved oxygen content is computed as a function of upstream oxygen content, deoxygenation and reaeration between stations, and any new oxygen added (in water inflow) at the point.

In time period 3, once again new flows, pollution loads, and oxygen levels are read in or computed for initial stations. Values are then computed for those downstream stations defined in the preceding paragraph, and in addition for all downstream stations for which the distance below the nearest initial station divided by velocity equals 2; and so on from time period to time period, with new downstream stations being included as the "stream flow" reaches them. Flows therefore "enter" a "dry" stream at initial stations and flow downward toward the mouth. Flows on tributaries (as well as their waste loads and oxygen contents) are added to mainstream flows at confluences.

Flow and quality "histories" can then be derived and used in numerous ways. Steady flows at various design levels can serve as inputs, and stations can be defined so as to sample stream quality at any points desired. More realism could be introduced by allowing stream flow to vary in a synthetic hydrology statistically based on past records or in a "rerun" of the actual recorded flow.

Although it is not intended in the present study to do any empirical measurement of the deoxygenation and reoxygenation constants (k_1 and k_2), it is possible to run the simulation models with alternative assumptions of these constants so that possible errors due to their misestimation can be quantitatively assessed.

The preceding statement describes the basic stream flow and quality program which is now operative. There are several important features to be emphasized in using the model as a water policy planning tool.

1. A test in the program after every printout of information for a station compares D.O. and/or B.O.D. levels as computed with specified standards introduced as inputs. The test allows simulation to proceed until a station is reached where standards are not met; at this point initial flows can be raised by a stipulated per-

centage and a new simulation begun. This process is repeated until D.O. and B.O.D. meet standards at all stations, when the program terminates. At termination, the final percentage by which initial flows has been raised will be printed, as well as the annual cost of storage required to raise flows by that amount.

By the introduction of successively more stringent standards, a curve can then be made of percentage flow increases as functions of quality standards.

2. A repeat loop has been introduced to facilitate sensitivity testing of various parameters of the system. This loop allows automatic reruns with successive increments of parameters such as the k_1 and k_2 constants in the oxygen sag equation; the velocity of streamflow; as well as input variables such as the B.O.D. discharge at specific stations. If desirable, this may be designed so as to allow simultaneous variation of more than one element of the system.

The value of such testing is two-fold. The importance of possible errors in the various parameters can be demonstrated, and functional relations between certain input variables and the flow required to meet standards can be derived.

3. Another added feature is explicit treatment of B.O.D. waste discharges as functions of levels of waste treatment. This allows derivation of relations between waste treatment levels and required flow increases to meet stipulated standards at all stream points.

4. As noted briefly above, the model now contains cost functions for both (1) levels of waste treatment and (2) storage required to raise minimum flows by varying percentages, and it is

therefore possible to test for minimum total treatment plus storage costs a stream system with various alternative assumptions of parameters, and with varying spacing of waste discharges.

It seems important to conclude with a discussion of what can not be done by this program, even with its present complexity. There are several related research efforts being made in the United States at present, all of them apparently with somewhat different aims and approaches.[2]

Of first importance is the fact that the only pollutant being analyzed in this program is B.O.D. It seems to be widely agreed that this is the problem of most common occurrence, and also that effective treatment of B.O.D. will usually result in low levels of other pollutants. There are, however, important exceptions and it should be borne in mind that in particular stretches of particular streams a single organic or non-organic chemical, a source of bacterial infection, or the release of radioactive materials may completely overshadow in importance the B.O.D. content of the water. In addition, two sorts of pollution other than B.O.D. may be very common quality problems: first, silt content, both of natural and man-induced origin; second, the increase, with high B.O.D. treatment levels, of plant nutrients which feed algae with secondary oxygen demands of major importance.

Neither does this program handle the process of pollution transport and biological regime in all its known complexities. For example, the possibility of sludge deposition is not incorporated, nor are details of channel

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2. See, for example: A Systems Analysis Method for Water Quality Management by Flow Augmentation, by John L. Worley, U.S. Public Health Service, Columbia River Basin Project, Portland Oregon, June 1963.

form, point of waste discharge, diurnal fluctuations in flow or temperature, and numerous other important determinants of stream quality at any given point. While these are serious omissions, they may be partly overcome by the flexibility involved in a digital model and its ability to test the sensitivity of conclusions to possible error in various assumed parameters and input data.

The program has been developed for immediate application in aiding the water planning process in Maryland, and in the hope that it may be improved by further research and experience throughout the country.

A detailed description of the program, including its logical structure, input and output formats, and some experimental results is being published as a separate technical report.

Appendix C

Streamflows by Regions

The tables of this appendix show the data used to calculate aggregate freshwater supply for Maryland Regions in Chapter IX.

Because data on streamflow rates exist only where gaging stations have been operated, the flows of many streams were estimated by using rates of nearby gaged streams of roughly similar drainage area and topographic characteristics. For many small streams (especially those draining directly into the Chesapeake Bay) even the drainage area is not known, and these were omitted. Consequently, total drainage areas are smaller than regional areas and total streamflow has been understated for all regions. However, since the effective use of waters in the smaller streams is much more difficult, it was not felt that the understatement of supply was a serious one.

Note also that the data given in Table 2 of Chapter IX were aggregated from unrounded original estimates of individual streamflows and may therefore differ slightly from the totals shown in the tables in this Appendix.

Insofar as possible, streamflows are estimated at mouths of streams, or at the upper limit of salt water intrusion for streams discharging into the Chesapeake Bay.

Table C1

Streamflows, Region I, Southern Maryland

Name	Drains into	Drainage area at point of entry or exit (sq. mi.)	Mean flow rate (m.g.d./sq.mi.)	Flow (m.g.d.)		
				Mean	95%	7 day-10 yr.
Mattawoman Creek	Potomac	98.1	0.646	63.4	3.7	2.3
Nanjemoy Creek	"	78.0	0.646*	50.4	4.1	3.8
Port Tobacco Creek	"	28.2	0.646*	18.2	1.5	1.4
Zekiah Swamp	"	104.8	0.646*	67.7	5.5	5.1
Gilbert Creek	"	45.0	0.646*	29.1	2.3	2.2
Chaptico Creek	"	10.7	0.654	7.0	0.3	0.0
St. Clement Creek	"	21.9	0.646*	14.1	1.1	1.1
McIntosh Run	"	34.1	0.646*	22.0	1.8	1.6
St. Mary's River	"	24.0	0.641	15.4	1.9	1.2
Hall Creek	Patuxent	20.0	0.646*	12.9	1.7	1.2
Hunting Creek	"	28.7	0.646*	18.5	2.4	1.7
Swanson Creek (1/2 flow)	"	13.7	0.646*	8.8	1.1	0.8
Killpeck Creek	"	13.1	0.646*	8.5	1.1	0.8
Battle Creek	"	18.9	0.646*	12.2	1.6	1.1
St. Leonard Creek	"	10.5	0.646*	6.8	0.9	0.6
Total		549.7		355.0	31.0	24.9

* Flow rate estimated.

Table C2

Streamflows, Region II, Western Maryland

Name	Drains into	Drainage area at point of entry or exit (sq. mi.)	Mean flow rate (m.g.d./sq.mi.)	Flow (m.g.d.)		
				Mean	95%	7 day-10 yr.
Youghiogheny River	Ohio River System	396.9	1.417	562.5	84.1	45.1
Casselman River	"	68.7	1.189	81.7	3.2	1.0
Big Piney Creek	"	23.6	1.000	23.6	0.4	0.1
Savage River	Potomac	115.3	0.930	107.3	2.7	1.2
George's Creek	"	73.9	0.680	50.3	3.4	1.8
Wills Creek	"	253.6	0.815	206.7	15.2	7.9
Evitts Creek	"	94.0	0.646	60.7	5.8	3.8
Dry Run	"	22.5	0.646*	14.5	1.4	0.9
Town Creek	"	156.1	0.554	86.6	8.1	5.0
Fifteen Mile Creek	"	61.2	0.600*	36.8	0.4	0.0
Sideling Hill Creek	"	103.6	0.646*	66.9	5.4	3.0
Tonoloway Creek	"	25.9	0.602	15.6	0.1	0.0
Great Tonoloway Creek	"	113.6	0.646*	73.4	5.9	3.0
Licking Creek	"	213.1	0.678	144.7	11.5	5.7
Little Conococheague Creek	"	18.0	0.646*	11.6	0.1	0.0
Conococheague Creek	"	563.4	0.745	419.9	61.9	39.8
Marsh Run	"	20.2	0.646*	13.1	0.1	0.0
Antietam Creek	"	291.9	0.593	173.2	59.1	48.3
Israel Creek	"	13.1	0.646*	8.5	0.1	0.0
Catoctin Creek	"	120.6	0.731	88.2	3.6	0.9
Tuscarora Creek	"	20.5	0.646*	13.2	0.1	0.0
Monacacy River			0.716	694.7	73.7	38.4
Total		3,739.9		2,953.7	346.3	205.9
Potomac Mainstem at Frederick-Montgomery County Line		10,687.4		6,726.5	862.5	579.3

* Flow rate estimated.

Table C3

Streamflows, Region III, Baltimore Metropolitan

Name	Drains into	Drainage area at point of entry or exit (sq. mi.)	Mean flow rate (m.g.d./sq.mi.)	Flow (m.g.d.)		
				Mean	95%	7 day-10 yr.
Broad Creek	Susquehanna	41.4	0.841*	34.8	12.2	8.7
Deer Creek	"	170.7	0.841	143.7	50.3	36.2
Swan Creek	"	26.5	0.841*	22.3	7.8	5.6
Romney Creek	"	25.2	0.841*	21.2	7.4	5.3
Bush River	Chesapeake Bay	139.7	0.841*	117.4	45.2	29.3
Gunpowder River	"	471.5	0.840	396.2	114.2	76.2
Back River	"	62.4	0.782	48.8	14.1	12.1
Patapsco River	"	611.0	0.743	454.1	131.5	41.5
Severn River	"	68.9	0.872*	60.1	22.3	15.6
Magothy River	"	23.9	0.874	20.9	7.7	5.4
South River	"	66.1	0.878*	58.1	21.4	15.0
West River	"	32.4	0.872	28.3	10.5	7.3
Cattail Creek	Patuxent	28.5	0.666	19.0	4.4	2.3
Little Patuxent River	"	161.4	0.669	108.1	24.4	12.7
Lyons Creek	"	19.5	0.666*	13.0	2.5	1.5
Total		1,949.1		1,546.0	475.9	274.7

* Flow rate estimated.

Table C4

Streamflows, Region IV, Washington Metropolitan Area in Maryland

Name	Drains into	Drainage area at point of entry or exit (sq. mi.)	Mean flow rate (m.g.d./sq.mi.)	Flow (m.g.d.) Mean	95%	7 day-10 yr.
Little Monacacy River	Potomac	18.9	0.646*	12.2	1.2	0.7
Broad Run	"	14.6	0.643*	9.4	1.0	0.6
Seneca Creek	"	129.3	0.600	77.6	14.8	6.7
Muddy Branch	"	19.2	0.646*	12.4	1.2	0.7
Watts Branch	"	22.3	0.646*	14.4	1.4	0.7
Cabin John Branch	"	25.6	0.646*	16.5	1.7	0.6
Rock Creek	"	76.5	0.579	44.3	6.9	1.9
Anacostia River	"	169.9	0.503	85.6	8.0	3.3
Oxon River	"	13.5	0.646	8.7	0.8	0.2
Henson Creek	"	18.2	0.769	14.0	1.3	0.1
Broad Creek	"	30.0	0.646*	19.4	1.9	0.2
Piscataway Creek	"	70.4	0.646*	45.5	4.5	0.4
Western Branch	Patuxent	109.5	0.667	73.1	7.0	3.0
Mataponi Creek	"	19.7	0.664*	13.1	2.5	1.6
Swanson Creek (1/2 flow)	"	13.7	0.664*	9.1	1.8	1.0
Patuxent River[a]	Chesapeake Bay	181.2	0.665	120.6	23.4	14.0
Total		932.5		575.9	79.4	35.7

* Flow rate estimated.

[a] At confluence with Little Patuxent River. This underestimates flow of Patuxent at upper limit of salt water intrusion (approximately Anne Arundel-Calvert County boundary).

Table C5

Streamflows, Region V, Eastern Shore

Name	Drains into	Drainage area at point of entry or exit (sq. mi.)	Mean flow rate (m.g.d./sq.mi.)	Flow (m.g.d.)		
				Mean	95%	7 day-10 yr.
Elk River	Chesapeake Bay	105.6	0.920	97.2	21.2	13.0
Octuraro Creek	"	209.9	0.846	177.7	51.5	27.1
Principio Creek	"	18.4	0.842*	15.5	3.0	2.3
Northeast Creek	"	44.1	0.956	42.2	6.0	3.4
Bohemia Creek	"	34.9	0.653*	22.8	5.6	4.3
Sassafras River	"	17.2	0.600	10.3	4.9	4.3
Granny Finlay Branch	"	7.1	0.661*	4.7	1.1	0.9
Southeast Creek	"	14.2	0.653	9.3	2.0	1.6
Morgan Creek	"	32.4	0.608	19.7	6.5	4.4
Red Lion Branch	"	24.4	0.651*	15.9	3.9	3.0
Unicorn Branch	"	22.7	0.682	15.5	4.5	3.8
Andover Branch	"	95.4	0.774*	74.0	12.9	7.4
Cypress Branch	"	35.0	0.652	22.8	5.6	4.3
Wye River	"	24.4	0.659	16.1	3.5	2.4
Miles Creek	"	13.6	0.661*	9.0	2.2	1.7
Kings Creek	"	21.1	0.654*	13.8	3.4	2.6
Tuckahoe Creek	"	151.9	0.717	109.0	15.7	5.9
Hunting Creek	"	24.5	0.653*	16.0	3.9	3.0
Watts Creek	"	24.2	0.652*	15.8	3.9	3.0
Chapel Branch	"	18.2	0.652*	11.9	2.9	2.2
Forge Branch	"	18.5	0.654*	12.1	3.0	2.3
Choptank River	"	137.6	0.737	101.4	8.6	2.0
Transquaking River	"	25.0	0.716	17.9	4.0	3.1
Baron Creek	"	30.0	0.652*	19.6	4.8	3.7
Rewastico Creek	"	12.2	0.467	5.7	0.8	0.3
Quantico Creek	"	11.6	0.655*	7.6	1.9	1.4
Marshyhope Creek	"	214.0	0.775*	166.0	29.5	16.6
Nanticoke River	"	393.0	0.775	304.8	63.5	40.6
Tonytank Creek	"	11.8	0.652*	7.7	1.9	1.5
Beaverdam Creek	"	17.3	0.786	13.6	3.2	2.2
Wicomico River	"	42.1	0.775*	32.6	6.8	5.2
Wicomico Creek	"	32.1	0.651*	20.9	5.2	3.9
Manokin Branch	"	5.8	0.467	2.7	0.1	0.0
Pocomoke River	"	182.7	0.698	127.5	7.1	3.5
Dividing Creek	"	62.2	0.775*	48.2	8.4	4.8
Nassawango Creek	"	73.1	0.756	55.3	1.9	0.9
Total		2,208.2		1,662.8	314.9	192.6

* Flow rate estimated.

Appendix D

Waste Treatment:

Construction and Operating Costs

Table D1

Construction Costs: U.S. Total Estimated

Per Capita Cost in 1913 Dollars*

Plant Type	Population Size	Lower Limit	Mean	Upper Limit
Activated Sludge				
	10,000	3.37	4.87	7.03
	50,000	2.24	3.24	4.68
	100,000	1.88	2.72	3.93
Primary Settling				
	10,000	2.38	3.53	5.26
	50,000	2.01	2.98	4.44
	100,000	1.13	1.68	2.50
Trickling Filters				
	10,000	3.25	4.73	6.89
	50,000	2.07	3.02	4.40
	100,000	1.70	2.48	3.61

*Source: P.P. Rowan, K.H. Jenkins, and D.W. Butler, "Sewage Treatment Construction Costs," Journal of the Water Pollution Control Federation, June 1960, pp. 594-604.

Table D2

Construction Costs - 1960 Prices

(Using ENR Index, September 1960, Baltimore = 755)

Plant Type	Population Size	Lower Limit	Mean	Upper Limit
Activated Sludge	10,000	25.44	36.77	53.08
	50,000	16.91	24.46	35.33
	100,000	14.19	20.54	29.67
Primary Settling	10,000	17.97	26.65	39.71
	50,000	15.18	22.50	33.52
	100,000	8.53	12.68	18.88
Trickling Filters	10,000	24.54	35.71	52.02
	50,000	15.63	22.80	33.22
	100,000	12.84	18.72	27.26

Table D3

Annual* Construction Costs Per Capita:

1960 Prices

Plant Type	Population Size	Lower Limit	Mean	Upper Limit
Activated Sludge				
	10,000	1.14	1.65	2.39
	50,000	.76	1.10	1.59
	100,000	.64	.92	1.34
Primary Settling				
	10,000	.81	1.20	1.79
	50,000	.68	1.01	1.51
	100,000	.38	.57	.85
Trickling Filters				
	10,000	1.10	1.61	2.34
	50,000	.70	1.03	1.49
	100,000	.58	.84	1.23

*Construction costs per capita multiplied, following Wollman, (unpublished manuscript) by .045 to allow for amortization at 2% per annum over a 50-year life, and a 5% interest rate which averages 2 1/2% since the asset value steadily diminishes.

Table D4

Annual Operation and Maintenance Costs Per Capita*

Plant Type	Population Size	Lower Limit	Mean	Upper Limit
Activated Sludge				
	10,000	1.48	1.88	2.38
	50,000	1.07	1.36	1.72
	100,000	.95	.88	1.11
Primary Plants				
	10,000	.98	1.41	2.02
	50,000	.71	1.02	1.46
	100,000	.63	.91	1.30
Std. Rate Filters				
	10,000	.97	1.31	1.77
	50,000	.64	.86	1.16
	100,000	.56	.75	1.01

*Source: P.P. Rowan, K.L. Jenkins, and D.H. Howells, "Estimating Sewage Treatment Plant Operation and Maintenance Costs," _Journal of the Water Pollution Control Federation_, February, 1961, pp. 111-121.

Table D5

Total* Annual Treatment Costs Per Capita

Plant Type	Population Size	Lower Limit	Mean	Upper Limit
Activated Sludge				
	10,000	2.62	3.53	4.77
	50,000	1.83	2.46	3.31
	100,000	1.59	1.80	2.45
Primary Plants				
	10,000	1.79	2.61	3.81
	50,000	1.39	2.03	2.97
	100,000	1.01	1.48	2.15
Trickling Filters				
	10,000	2.07	2.92	4.11
	50,000	1.34	1.89	2.65
	100,000	1.14	1.59	2.24

*Construction plus operation and maintenance.